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Sugahara

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(45) **Date of Patent: Oct. 4, 2011**

(54) **LIQUID DROPLET TRANSPORTING APPARATUS, AND VALVE, MEMORY, DISPLAY UNIT USING THE LIQUID DROPLET TRANSPORTING APPARATUS**

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(73) Assignee: **Brother Kogyo Kabushiki Kaisha**, Aichi-Ken (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/044,732**

(22) Filed: **Mar. 10, 2011**

(65) **Prior Publication Data**

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Related U.S. Application Data

(62) Division of application No. 11/729,761, filed on Mar. 29, 2007, now Pat. No. 7,926,914.

(30) **Foreign Application Priority Data**

Mar. 31, 2006 (JP) 2006-097263

(51) **Int. Cl.**
B41J 2/06 (2006.01)

(52) **U.S. Cl.** **347/55**; 347/45; 347/54

(58) **Field of Classification Search** 347/19, 347/44, 45, 47, 54, 55, 61–65, 84–87, 70–71
See application file for complete search history.

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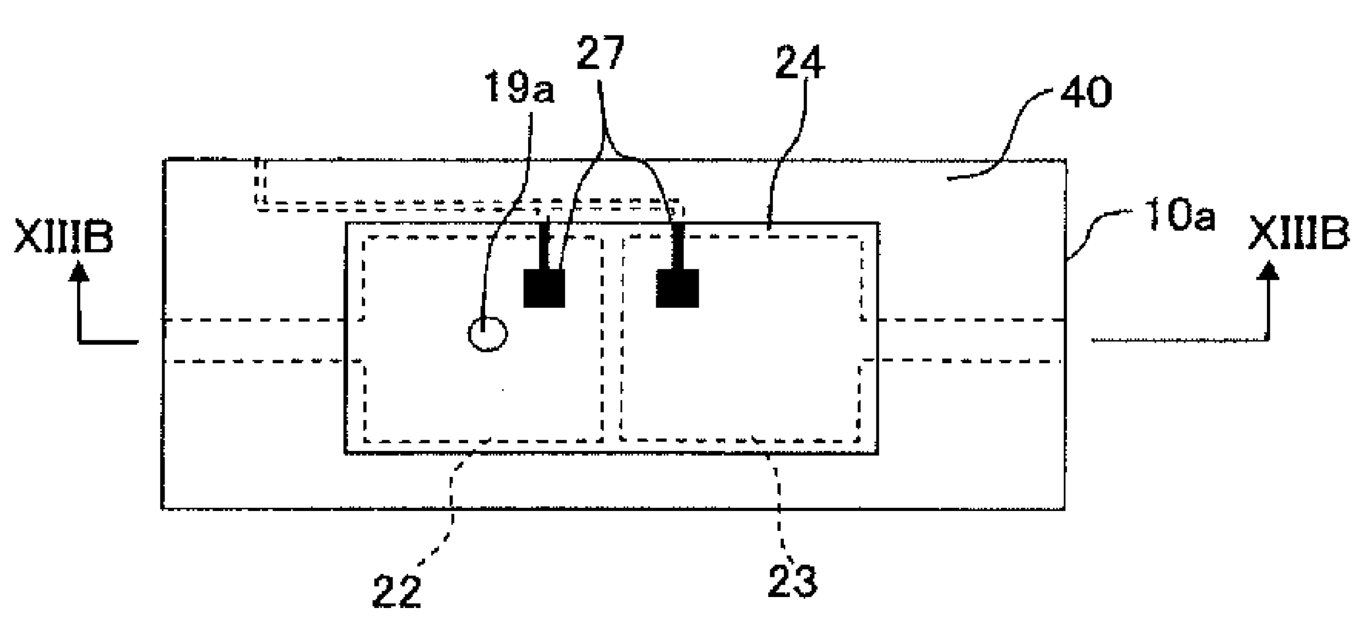
Primary Examiner — Juanita D Stephens
(74) *Attorney, Agent, or Firm* — Frommer Lawrence & Haug LLP

(57) **ABSTRACT**

A liquid droplet transporting apparatus includes a first electrode which is arranged on a surface of a substrate, a second electrode which is arranged apart from the first electrode on the surface of the substrate, an insulating layer which is arranged to cover each of the first electrode and the second electrode, and a liquid repellent property on a surface of the insulating layer changes according to an electric potential difference between the electrode and an electroconductive liquid droplet on the surface, and a third electrode which cooperates with the second electrode to detect the liquid droplet on the second electrode. Consequently, it is possible to transport a liquid droplet between two areas, and also to detect as to in which area out of the two areas, the liquid droplet exists.

2 Claims, 28 Drawing Sheets



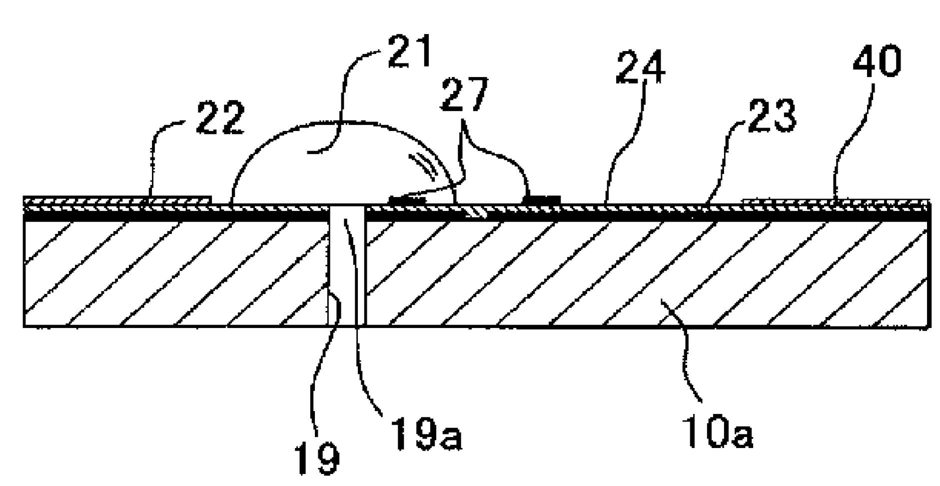


Fig. 1

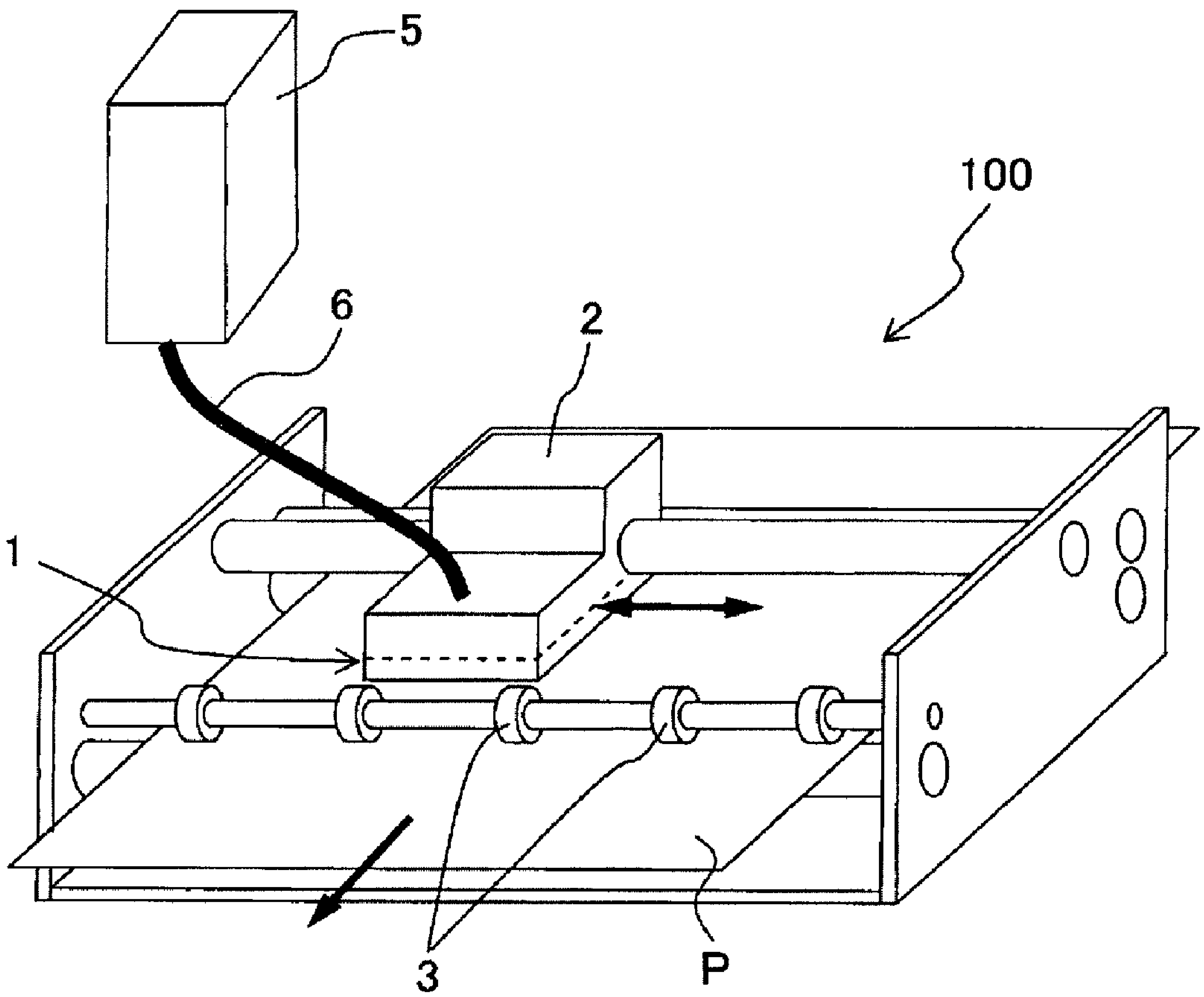


Fig. 2

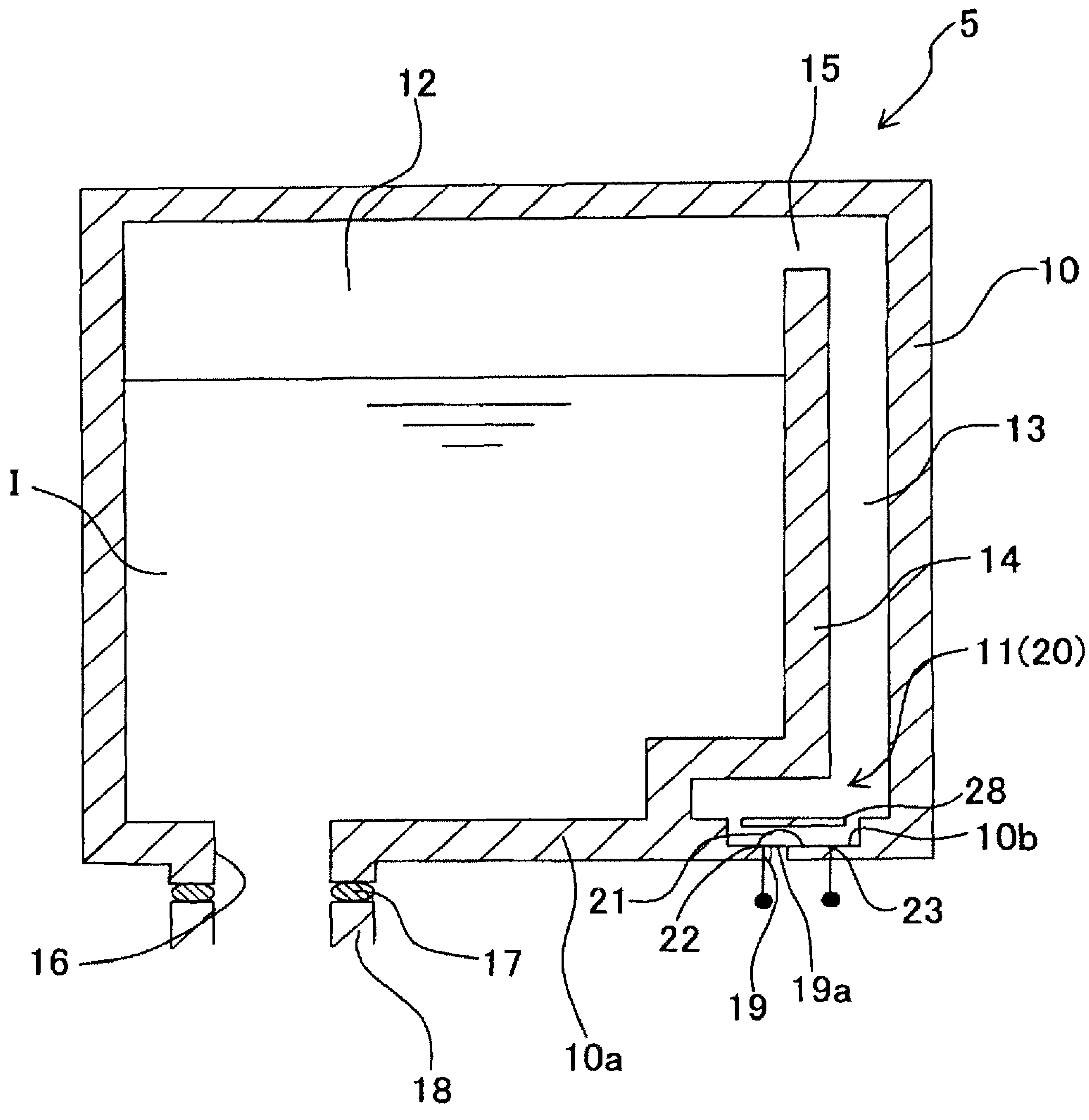


Fig. 3A

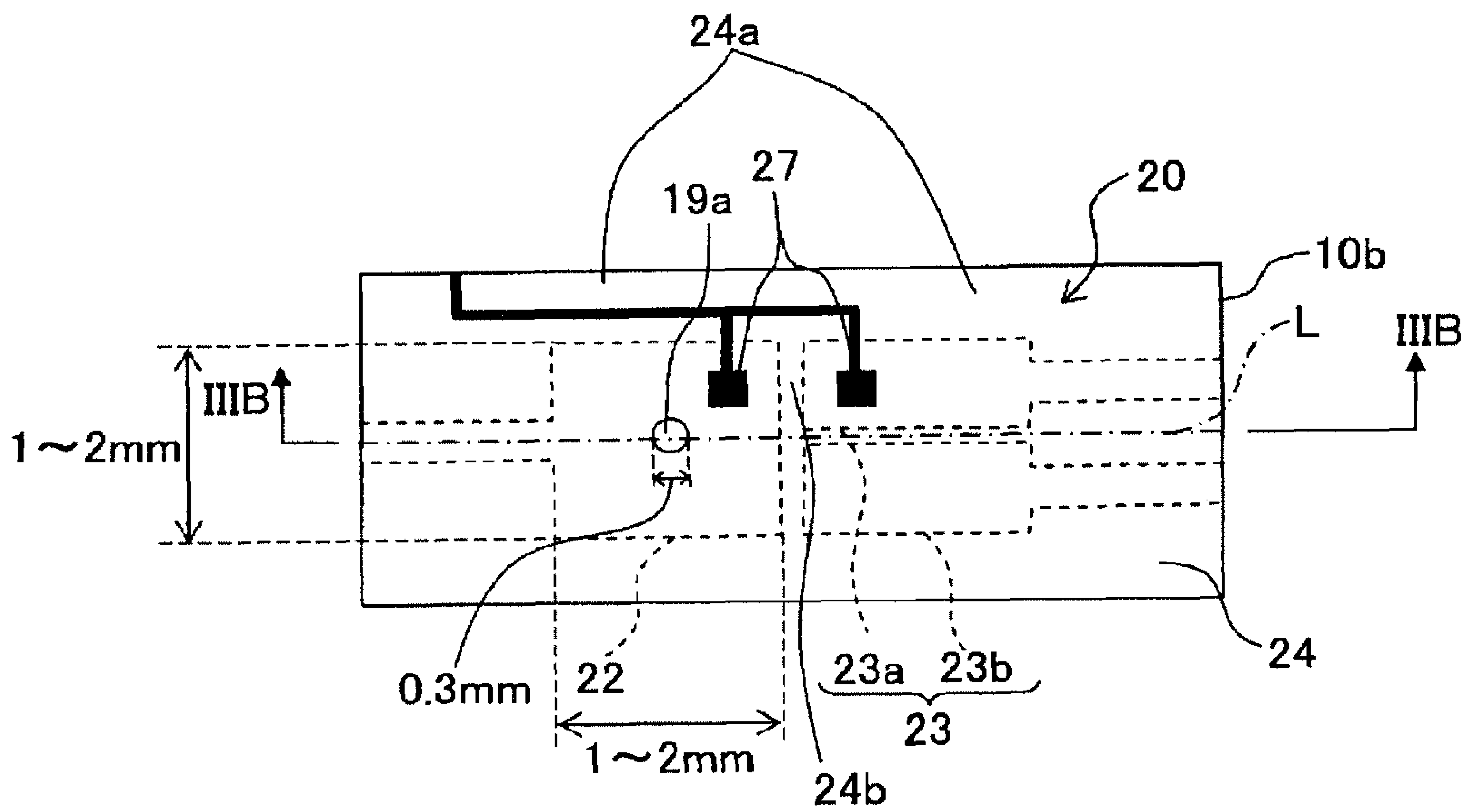
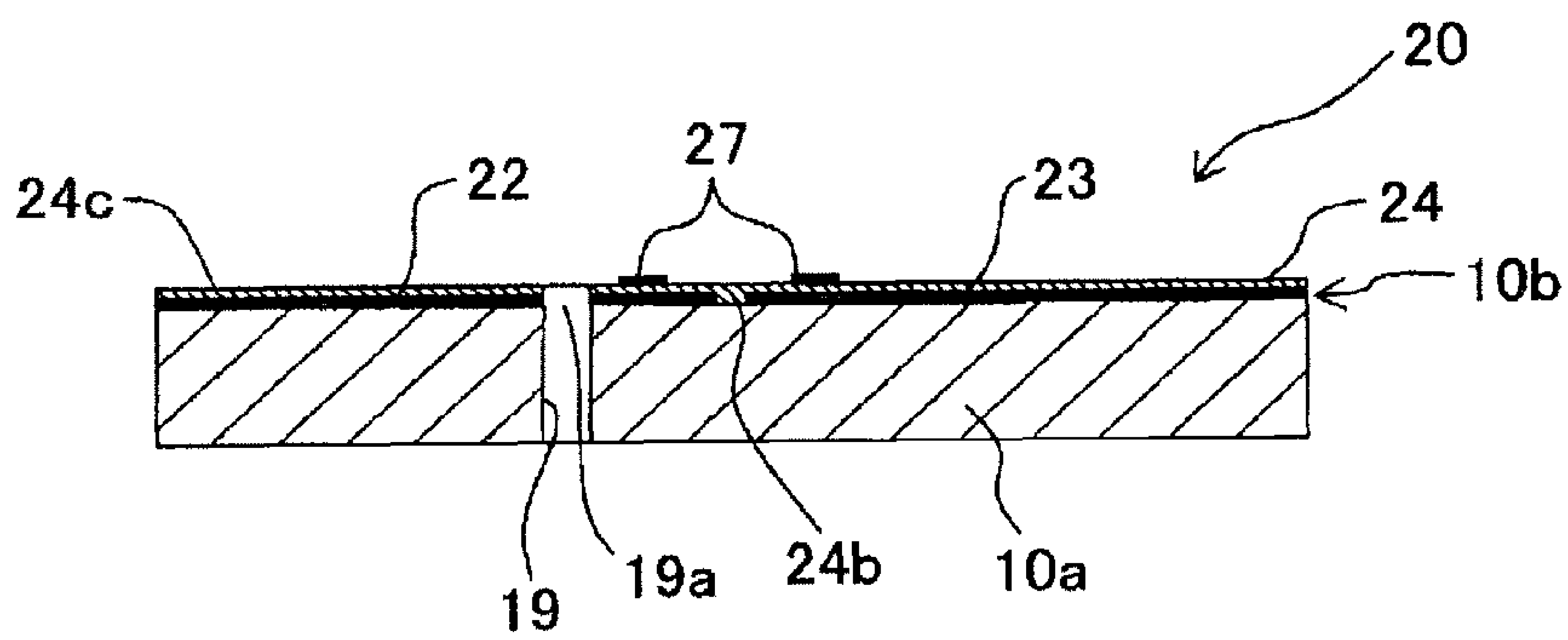

24a
27
19a
20
10b
L
IIIB
IIIB
1～2mm
0.3mm
22
23a
23b
23
24
1～2mm
24b

Fig. 3B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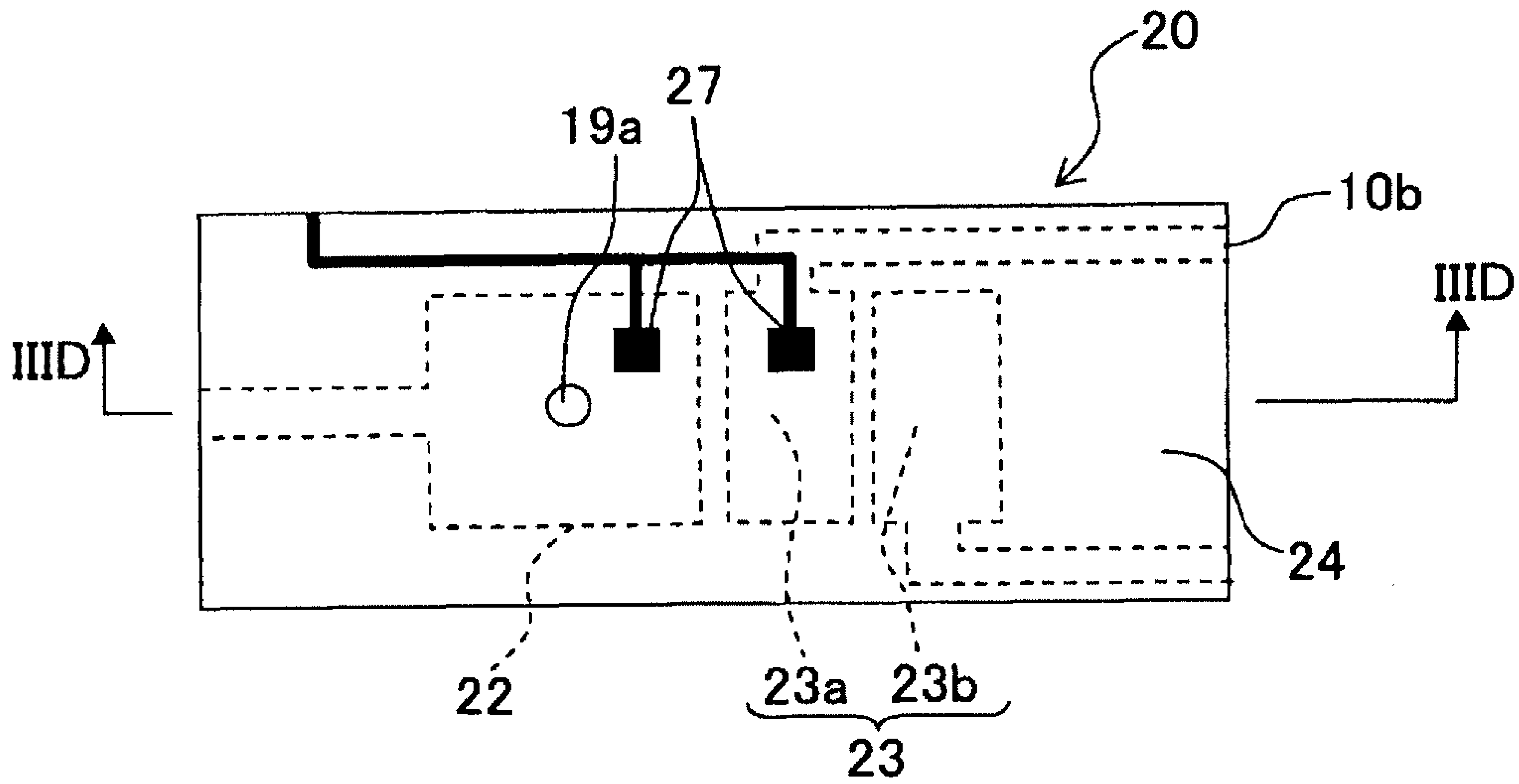
27
24c
22
23
24
10b
19
19a
24b
10a

Fig. 3C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IIID
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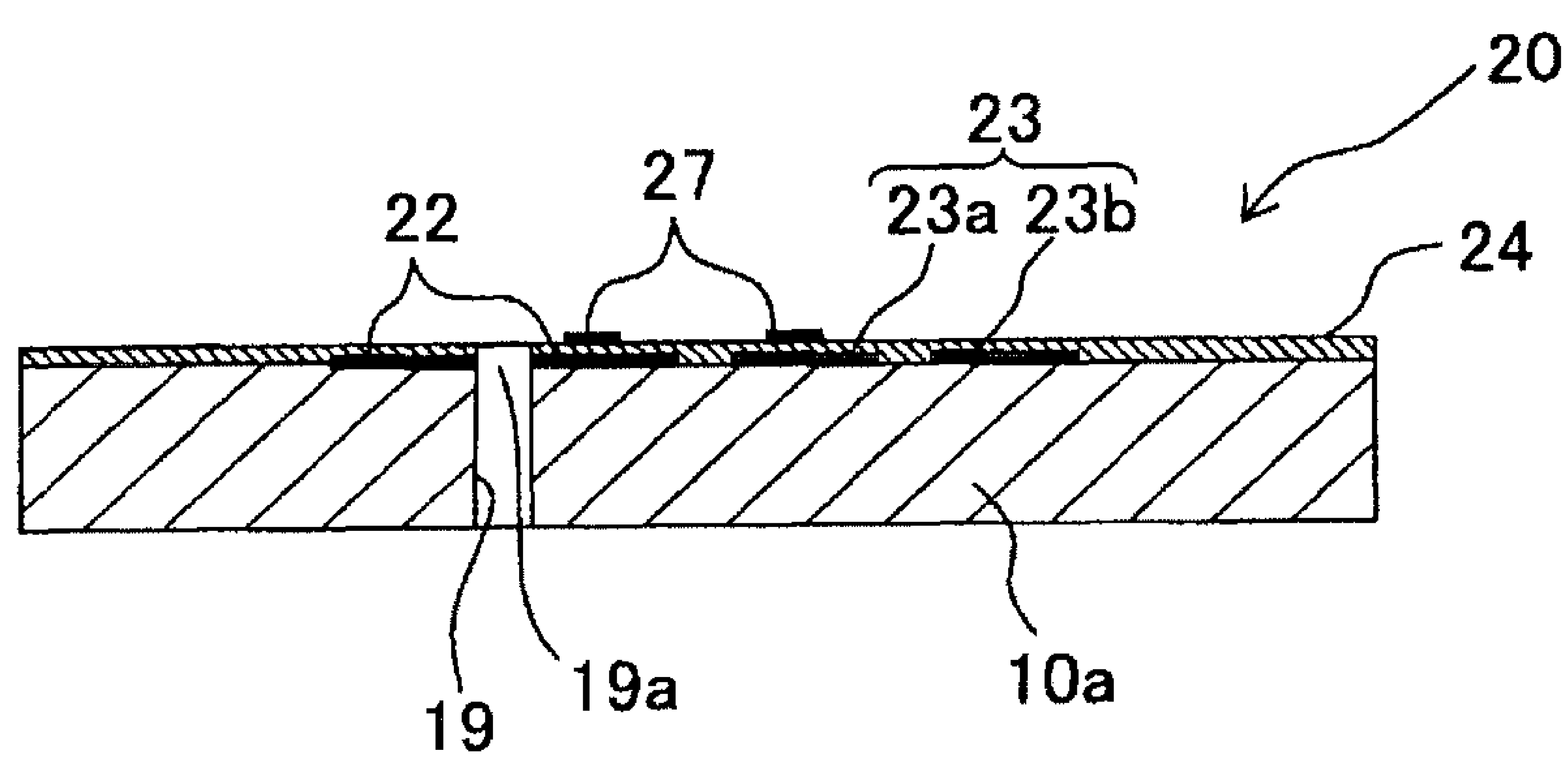
23a
23b
23

Fig. 3D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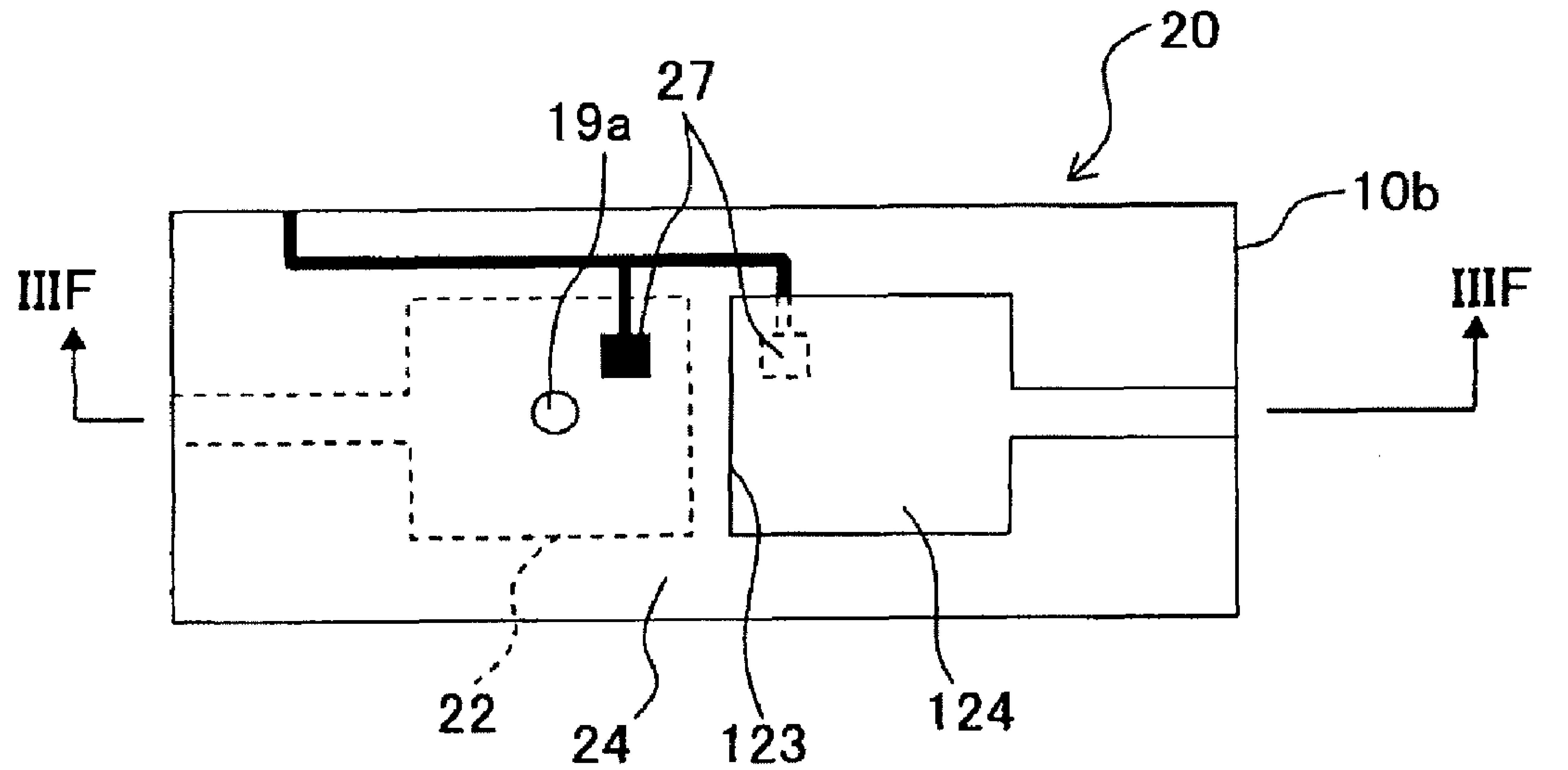
23
27
22
23a 23b
24
19
19a
10a

Fig. 3E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IIIF
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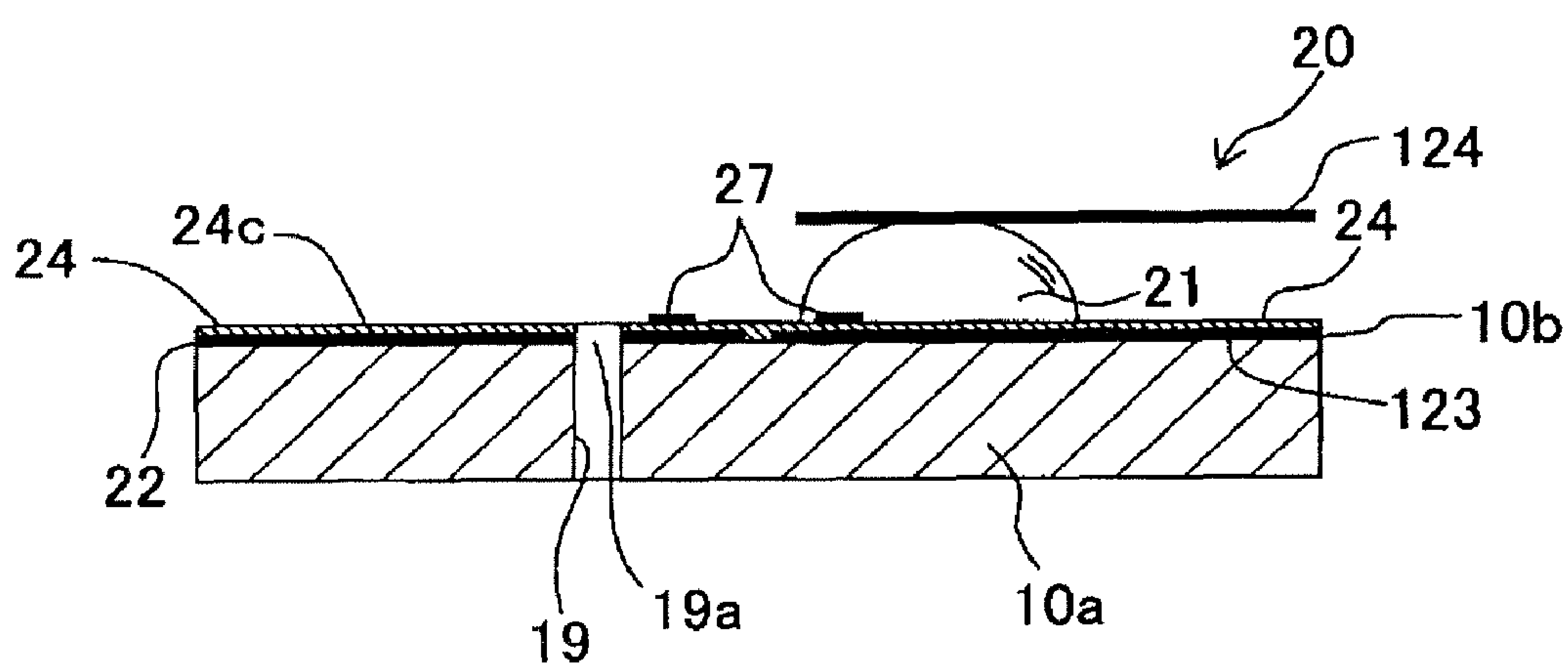
24
123
124

Fig. 3F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10b
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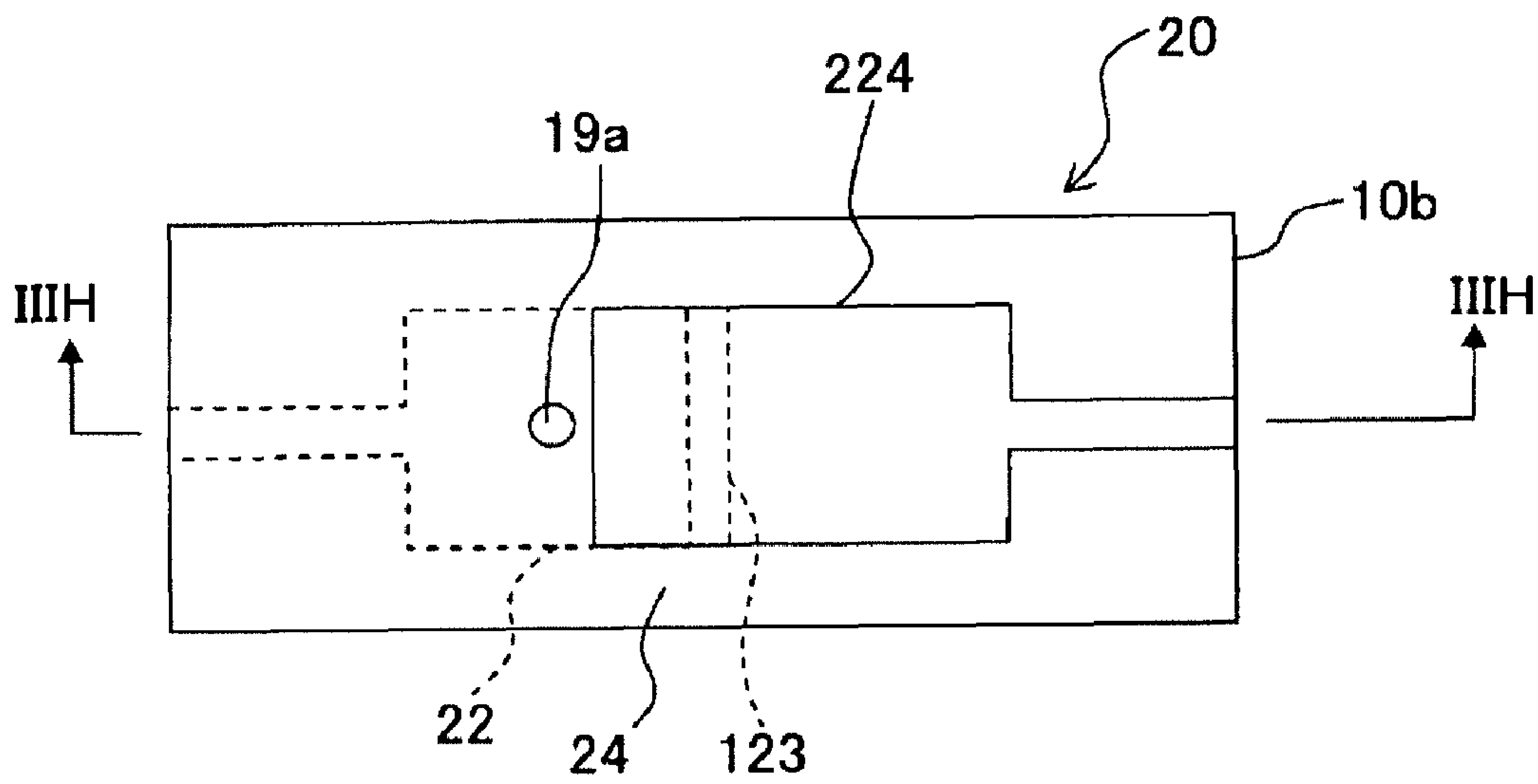
19
19a
10a

Fig. 3G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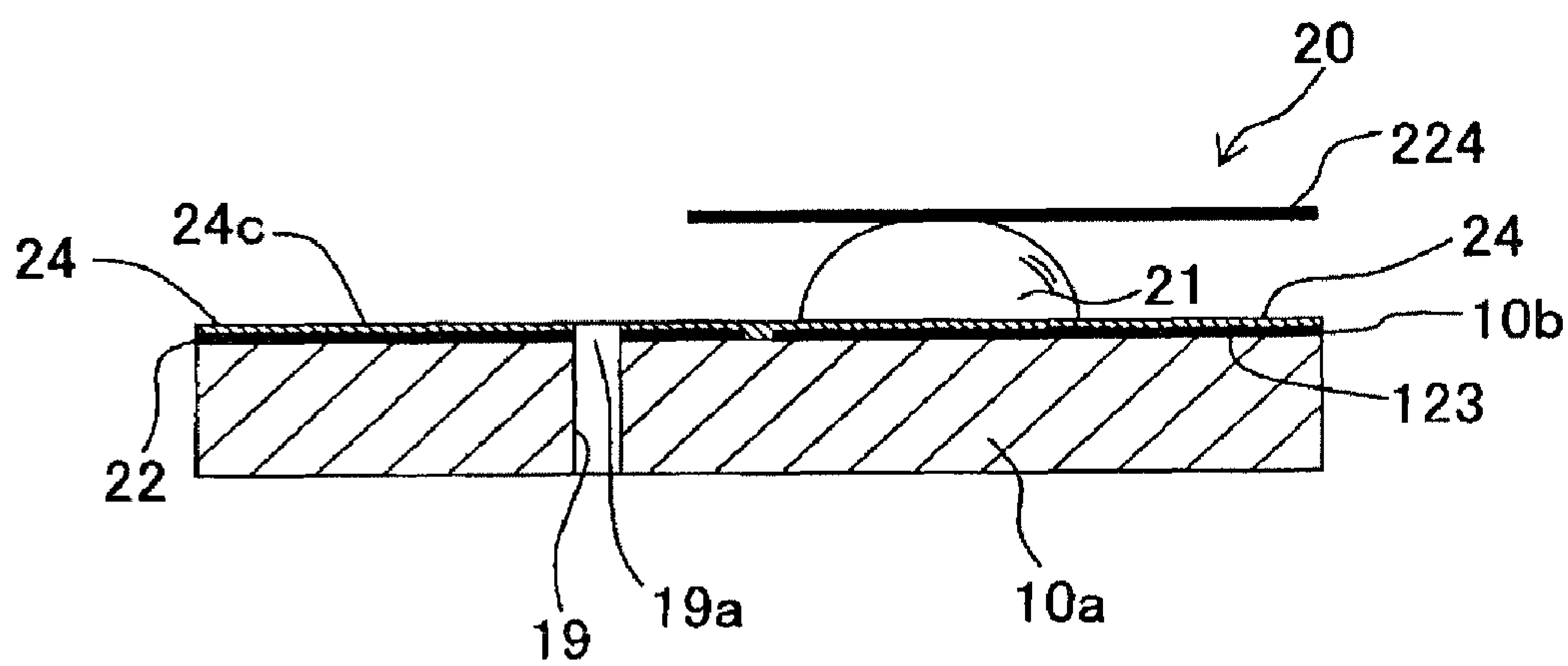
224
19a
10b
IIIH
IIIH
22
24
123

Fig. 3H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224
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24c
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10b
123
22
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19a
10a

Fig. 4

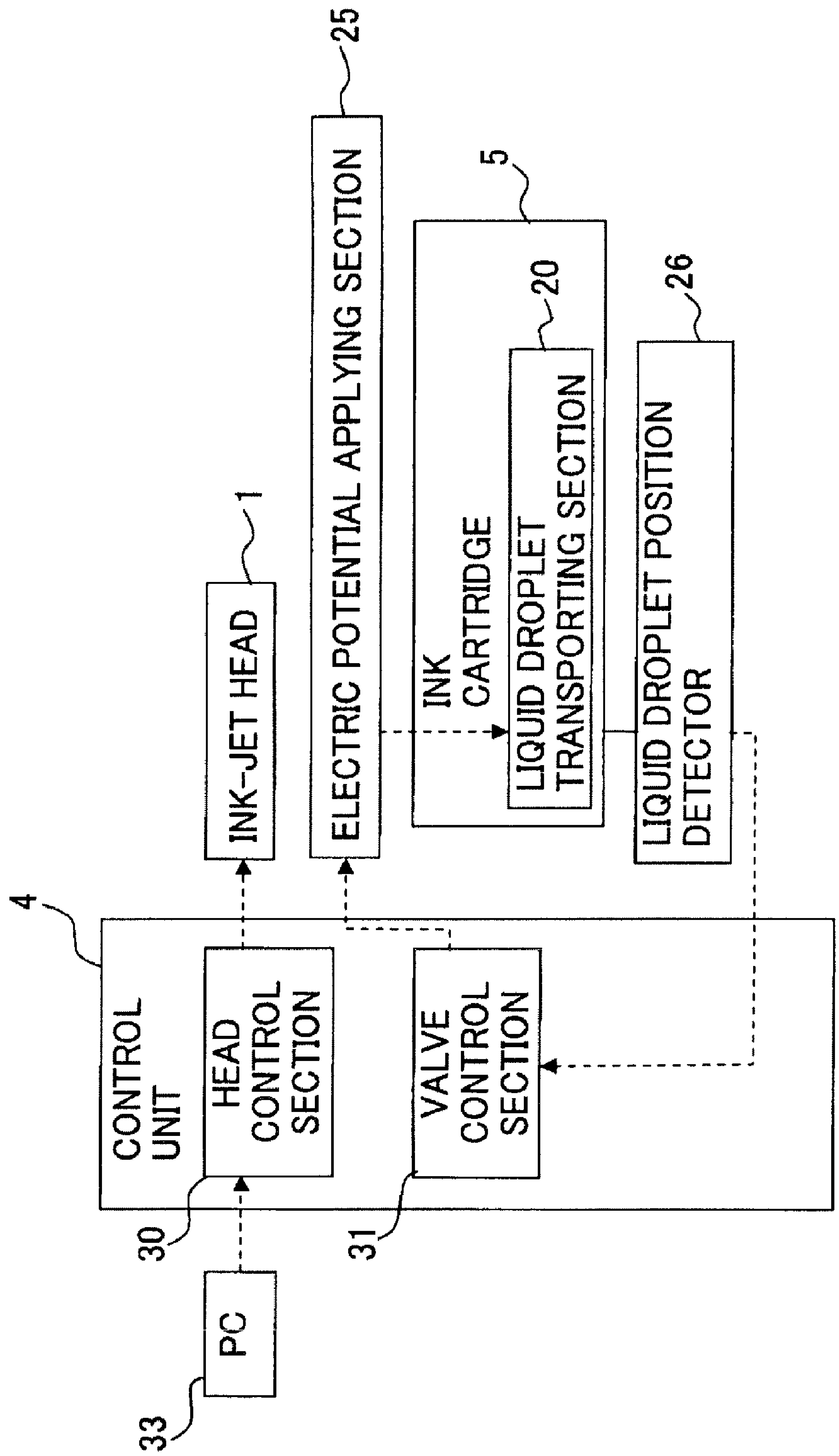

CONTROL UNIT
HEAD CONTROL SECTION
VALVE CONTROL SECTION
INK-JET HEAD
ELECTRIC POTENTIAL APPLYING SECTION
INK CARTRIDGE
LIQUID DROPLET TRANSPORTING SECTION
LIQUID DROPLET POSITION DETECTOR
PC
1
4
5
20
25
26
30
31
33

Fig. 5

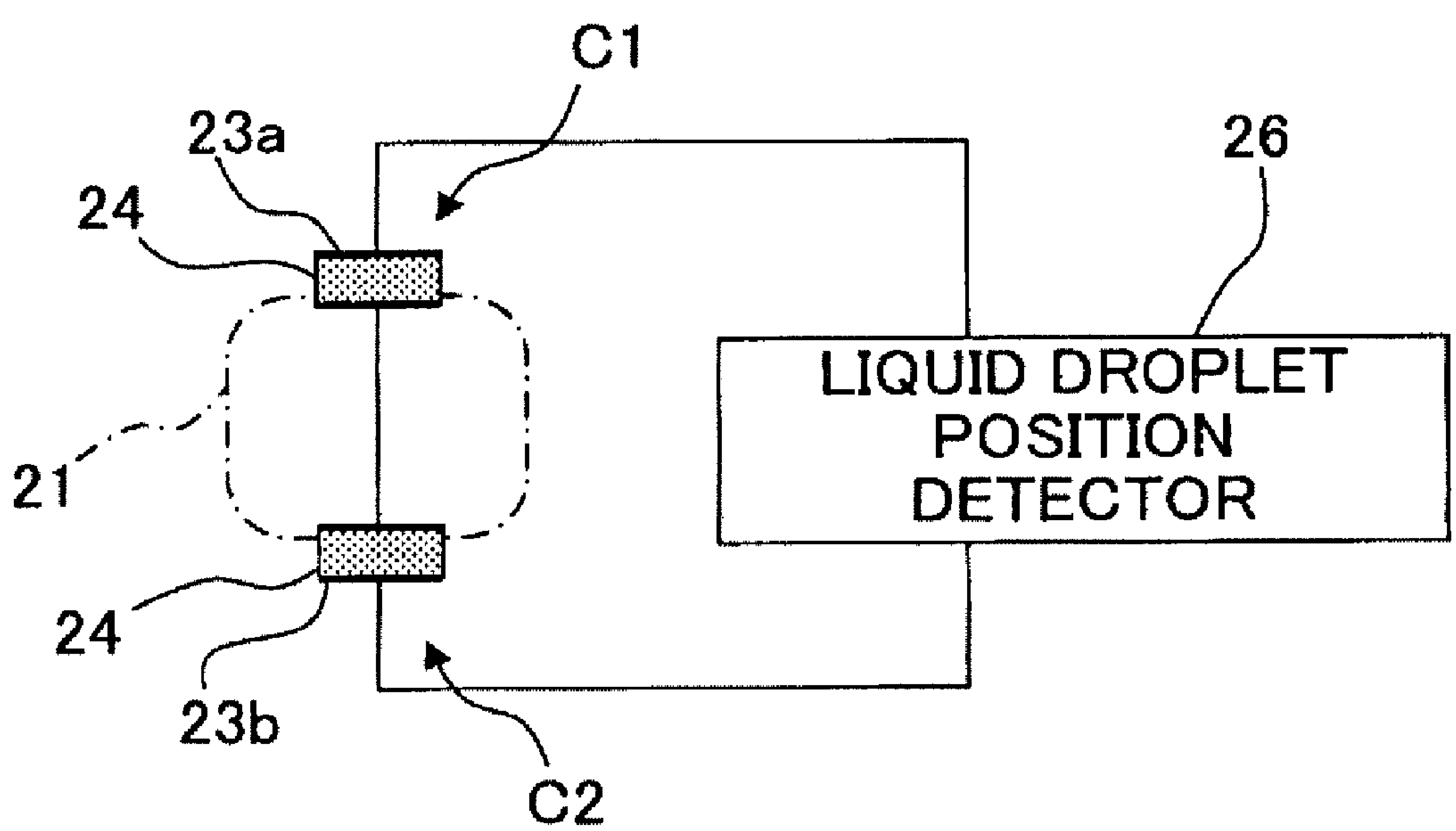
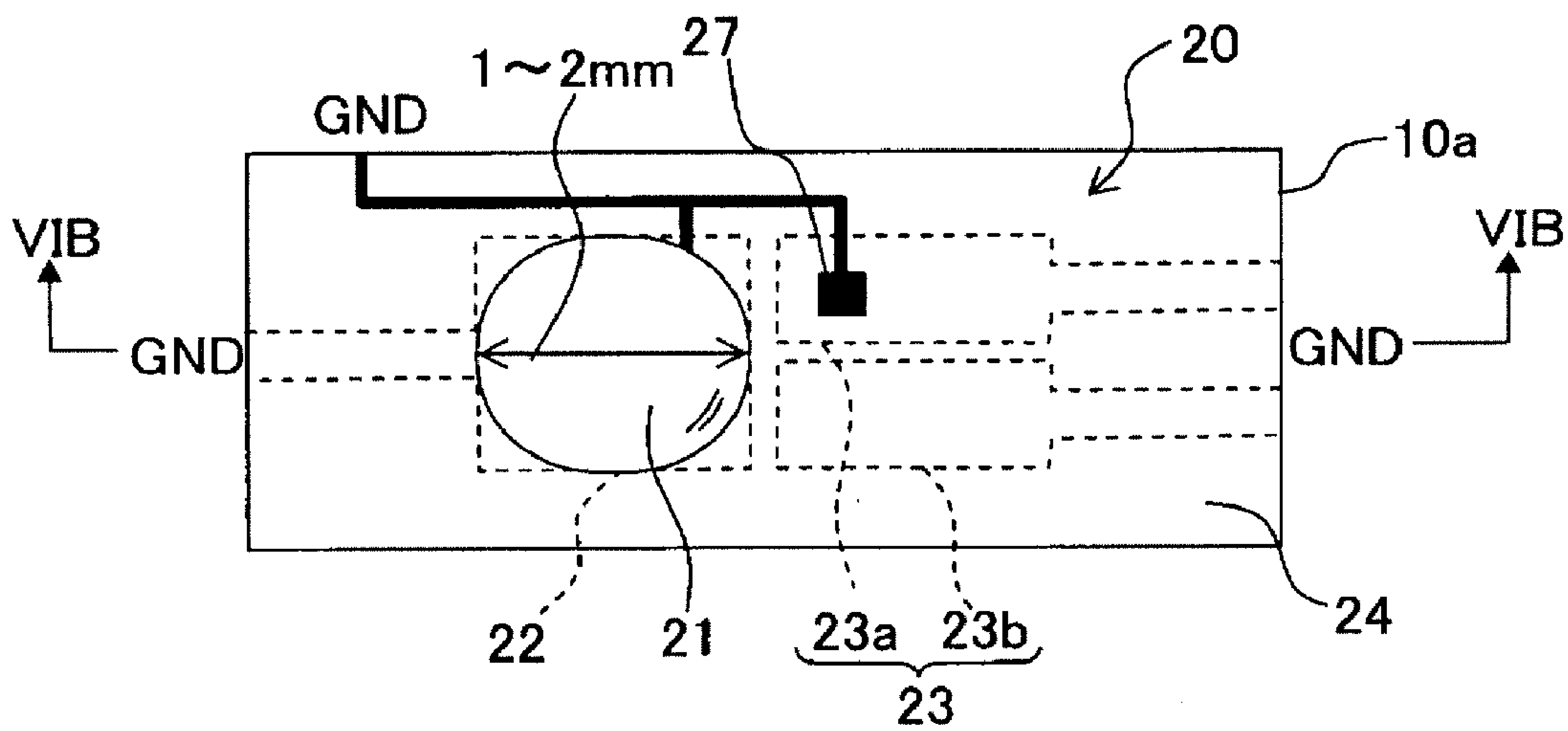
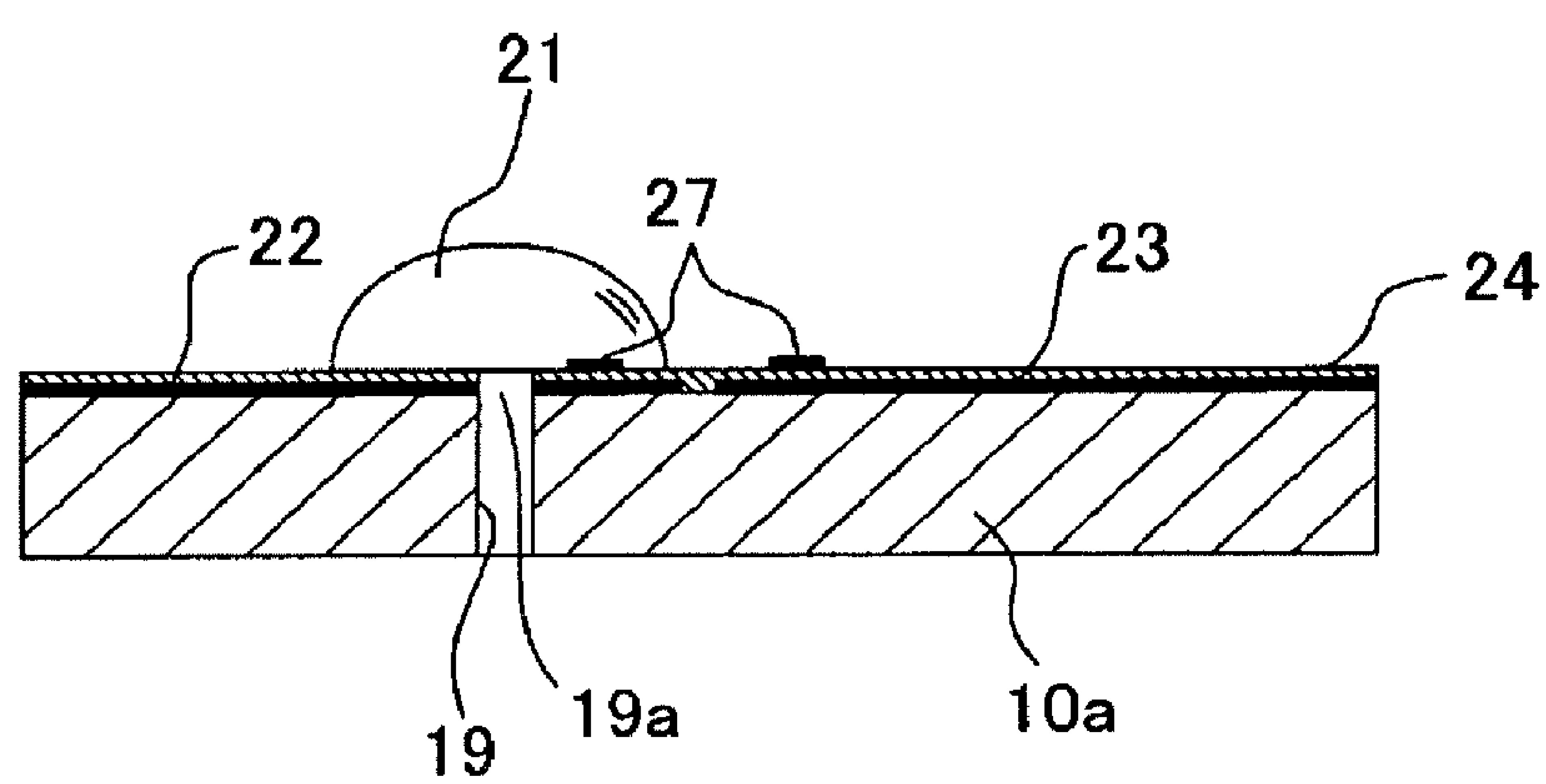


Fig. 6A



27
1～2mm
20
GND
10a
VIB
VIB
GND
GND
22
21
23a
23b
23
24

Fig. 6B



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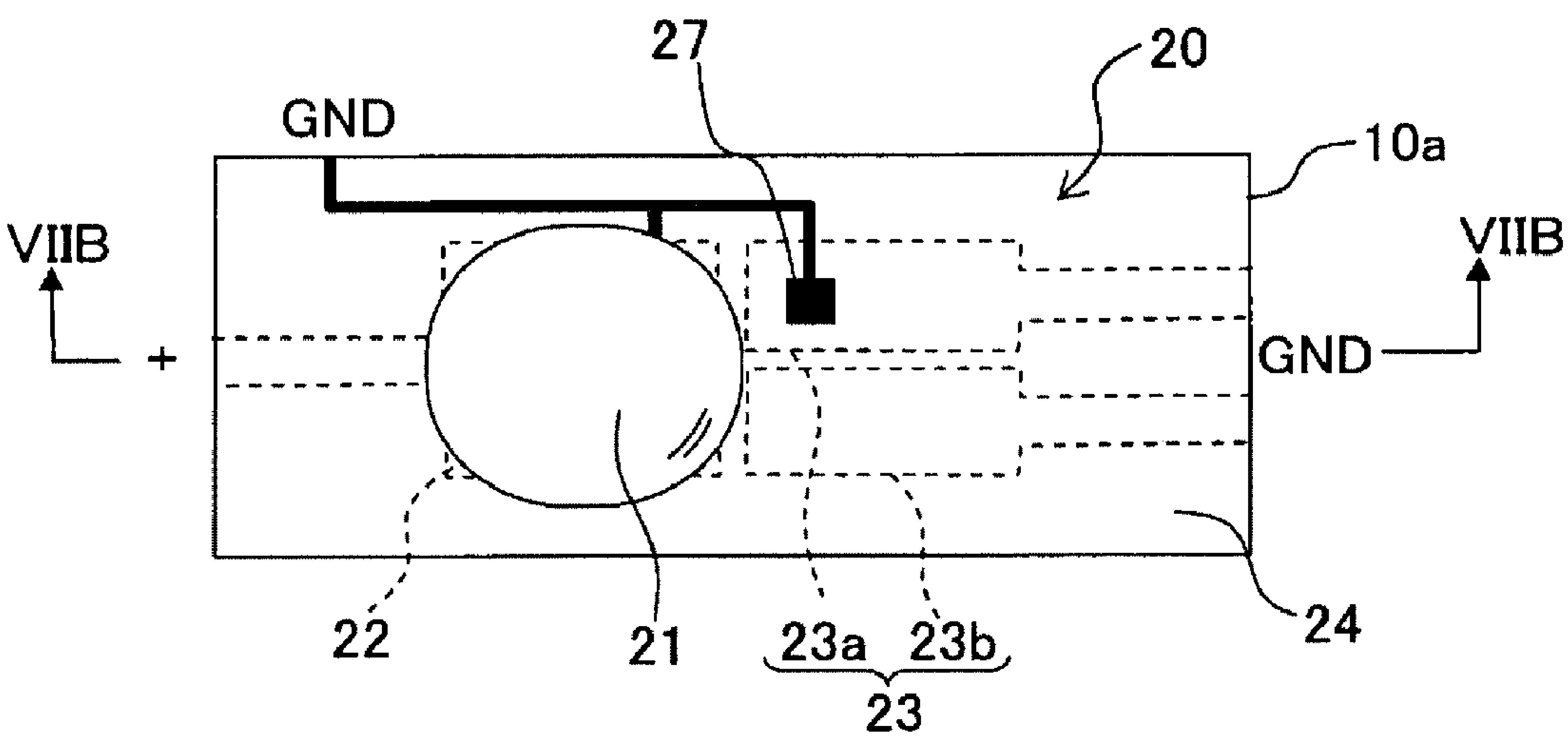
23
24
19
19a
10a

Fig. 7A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VIIB
+
VIIB
GND
22
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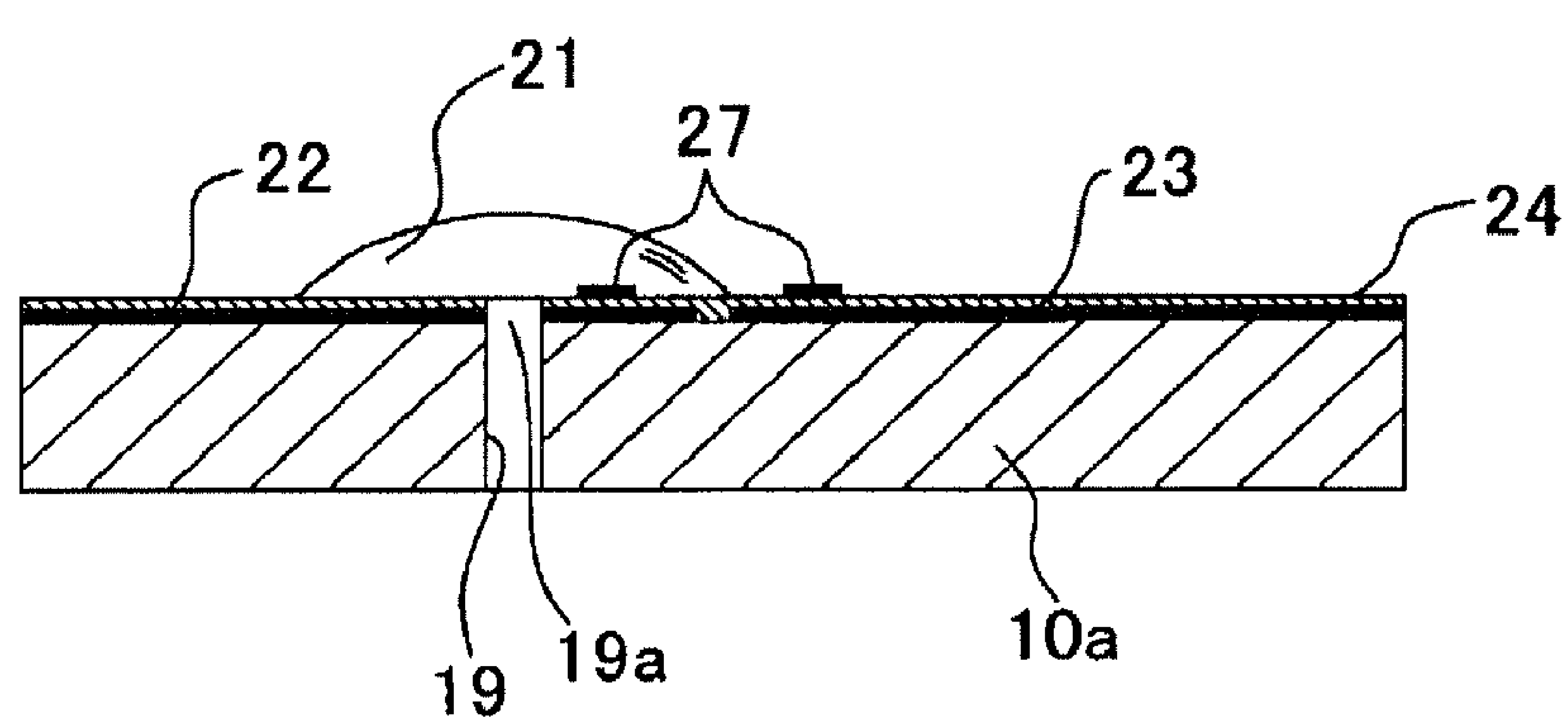
23a
23b
23
24

Fig. 7B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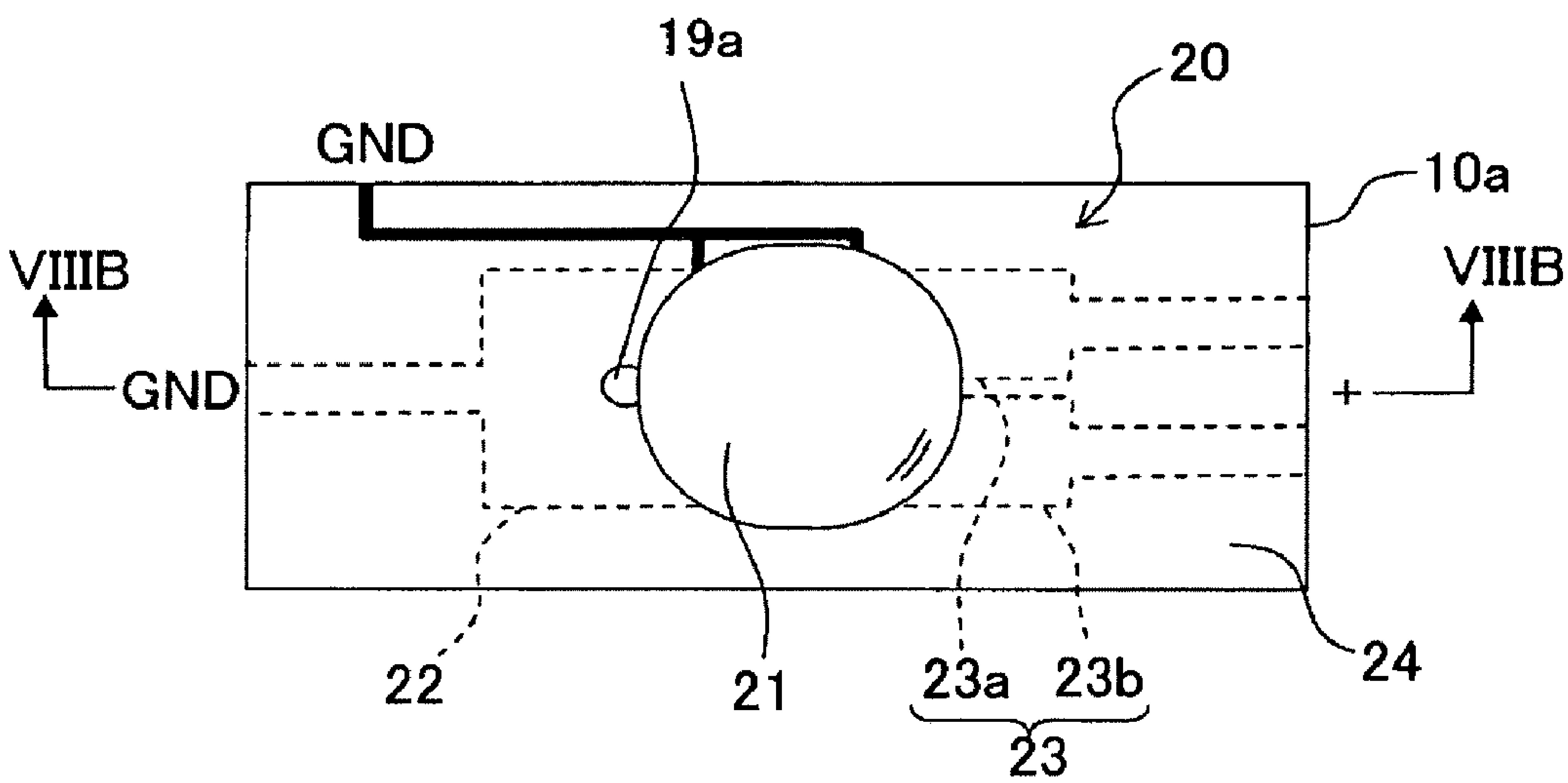
23
24
19
19a
10a

Fig. 8A


19a
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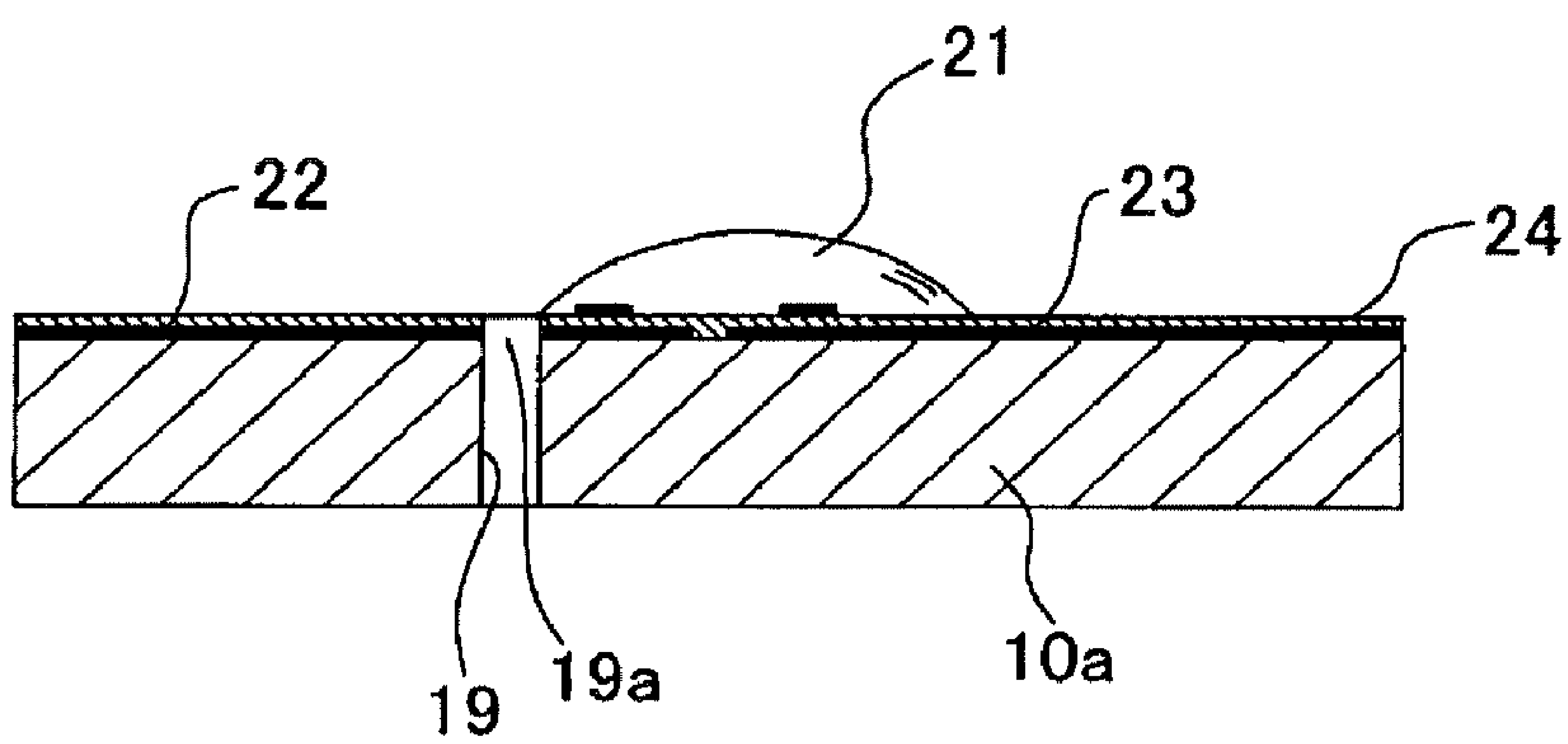
GND
10a
VIIIB
VIIIB
GND
+
22
21
23a
23b
23
24

Fig. 8B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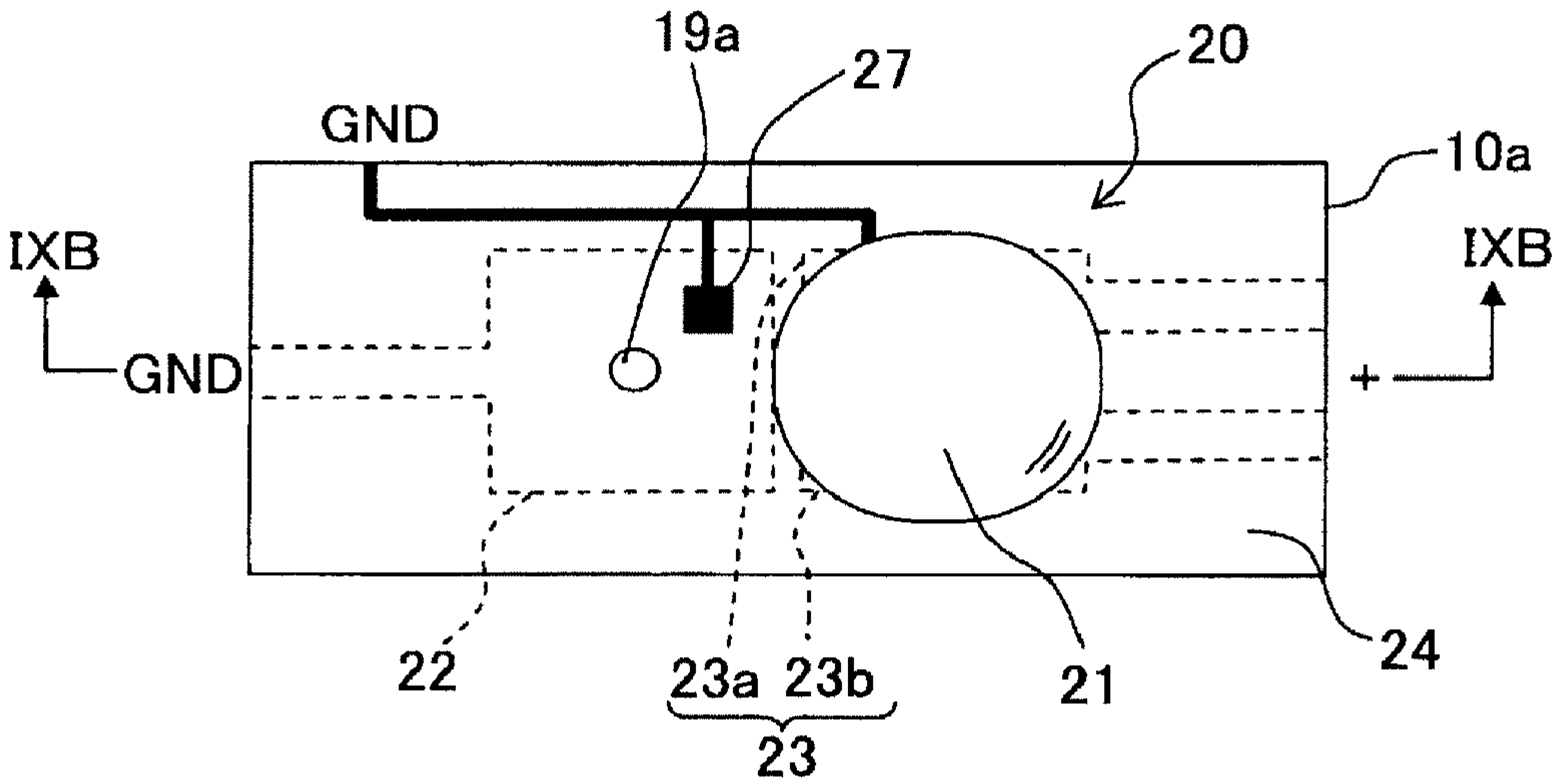
19a
10a

Fig. 9A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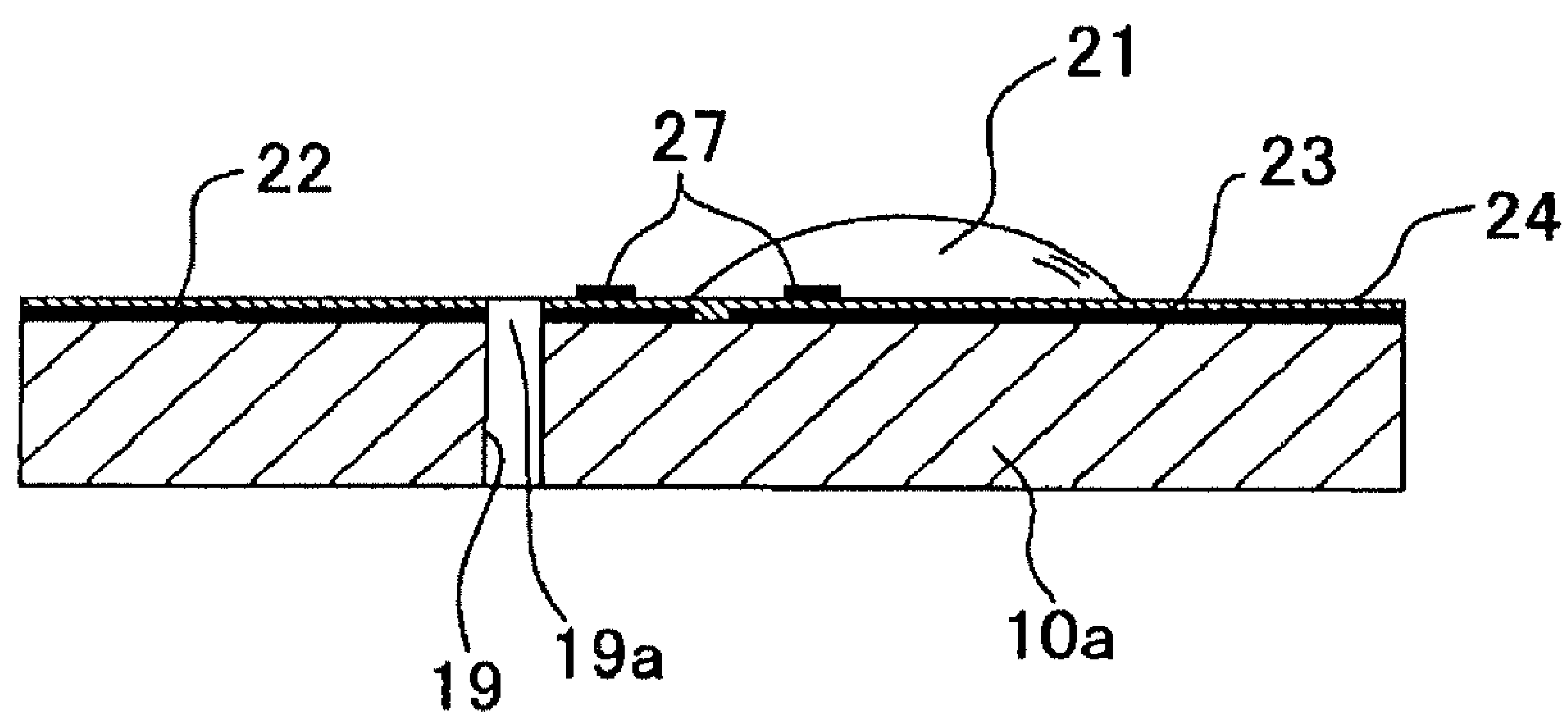
10a
IXB
IXB
GND
+
22
23a
23b
23
21
24

Fig. 9B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19a
10a

Fig. 10A

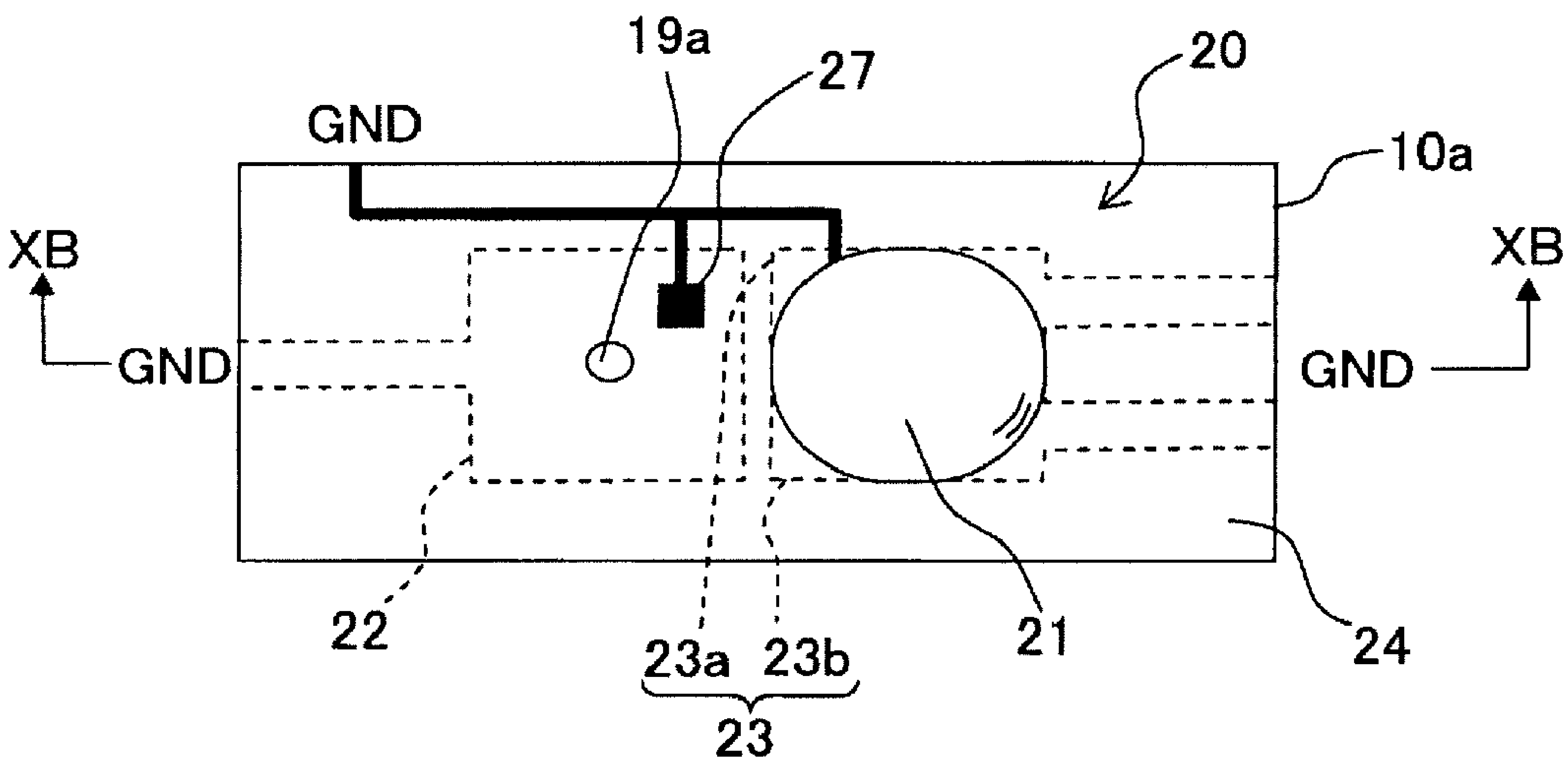


Fig. 10B

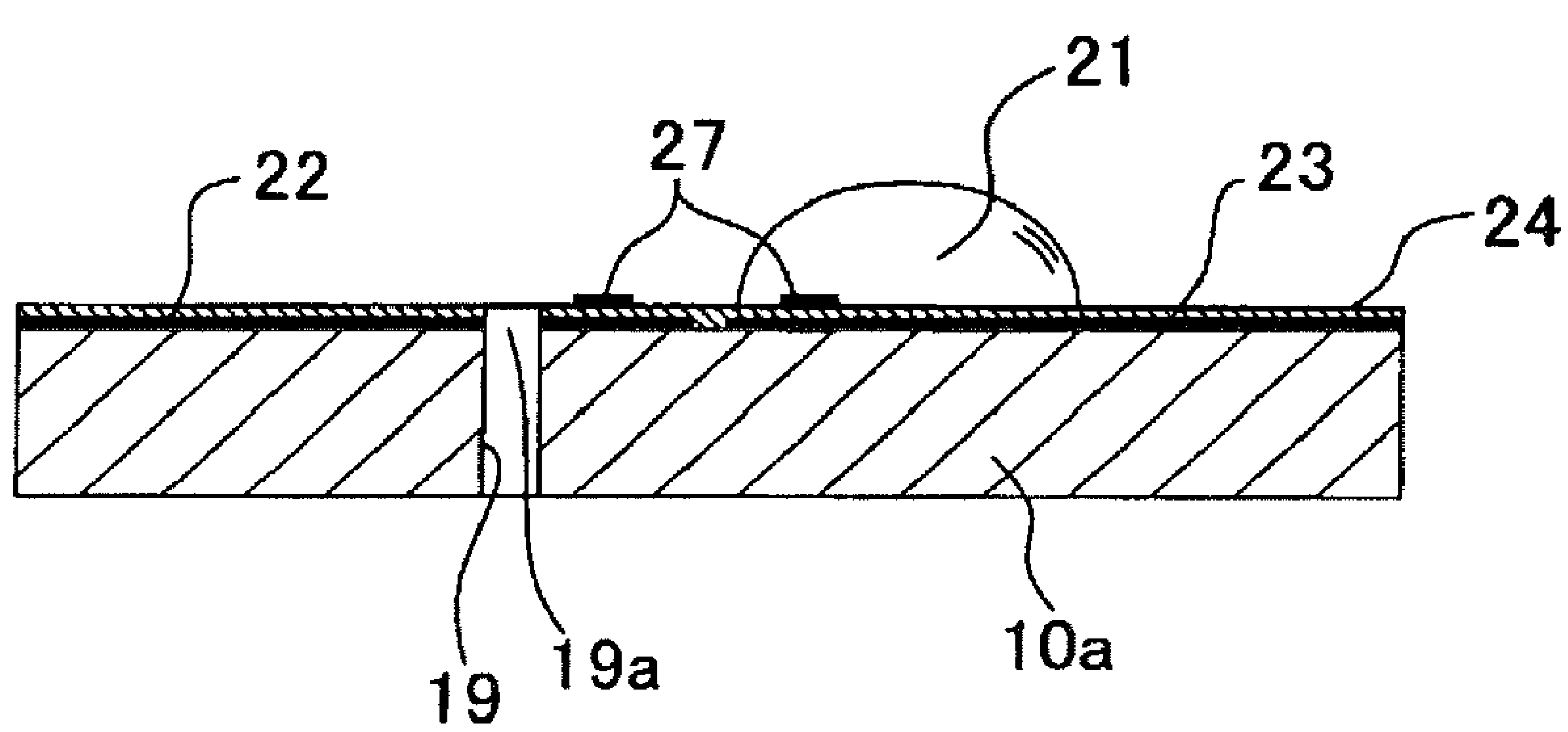


Fig. 11

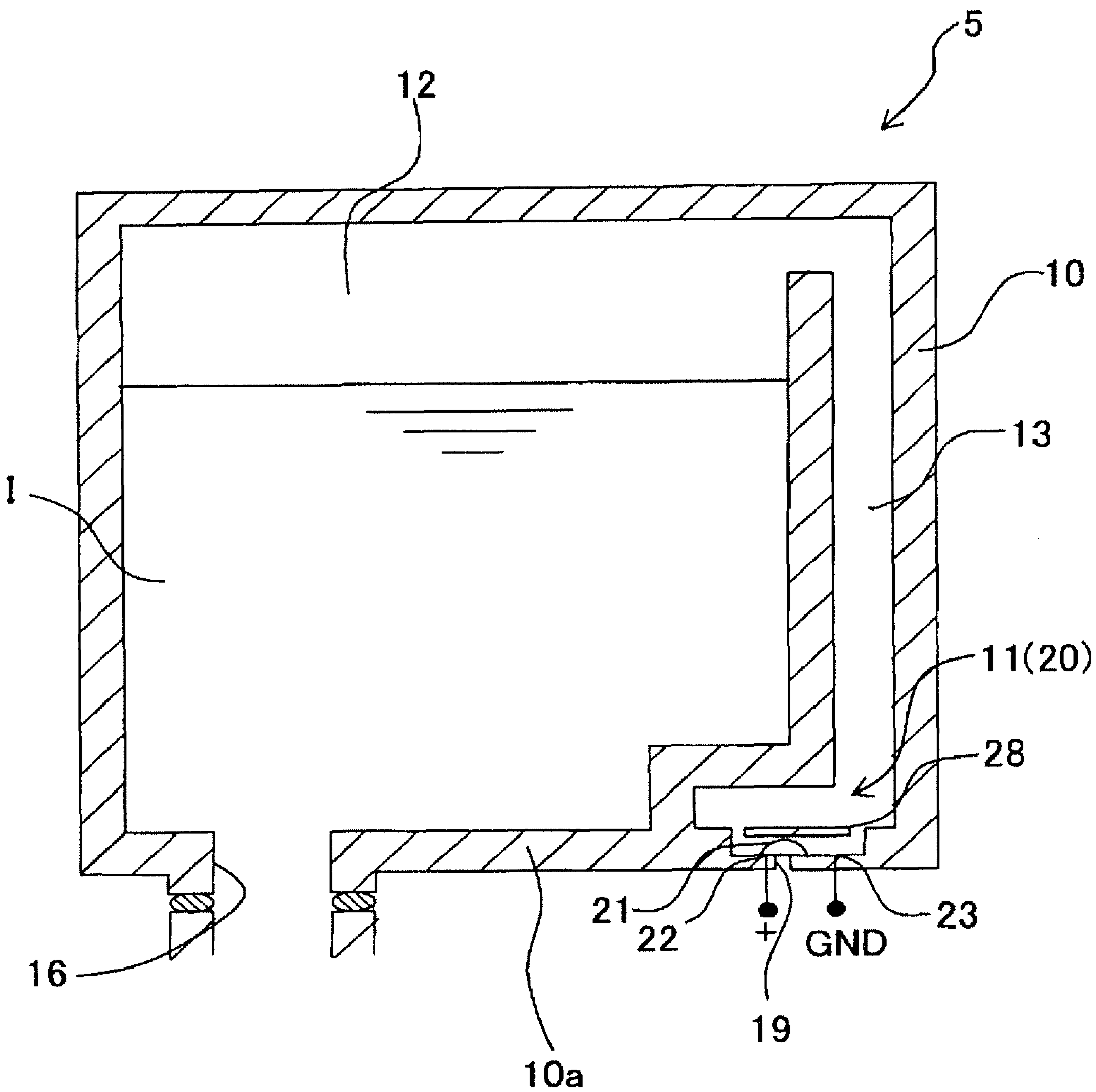


Fig. 12

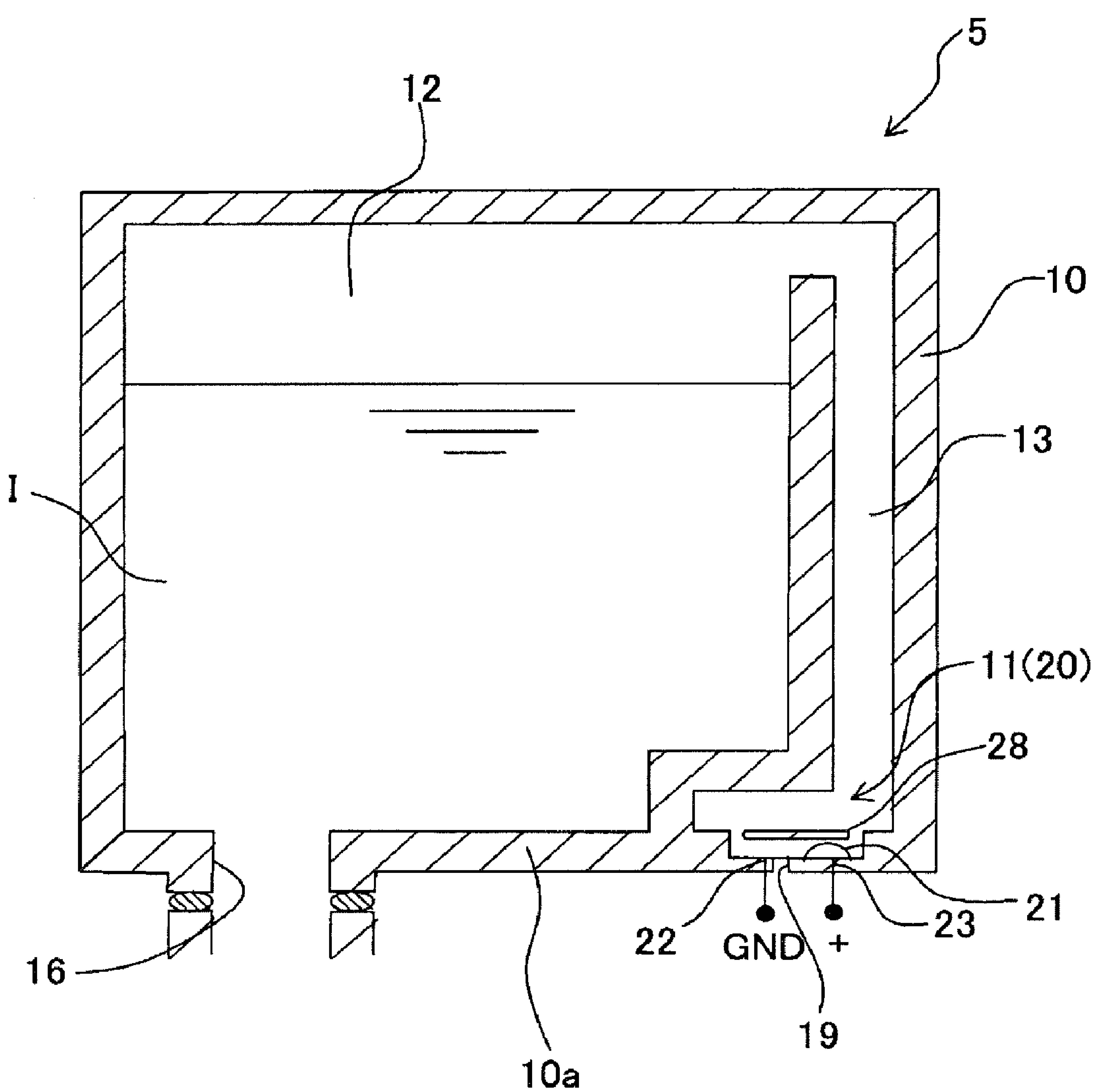


Fig. 13A

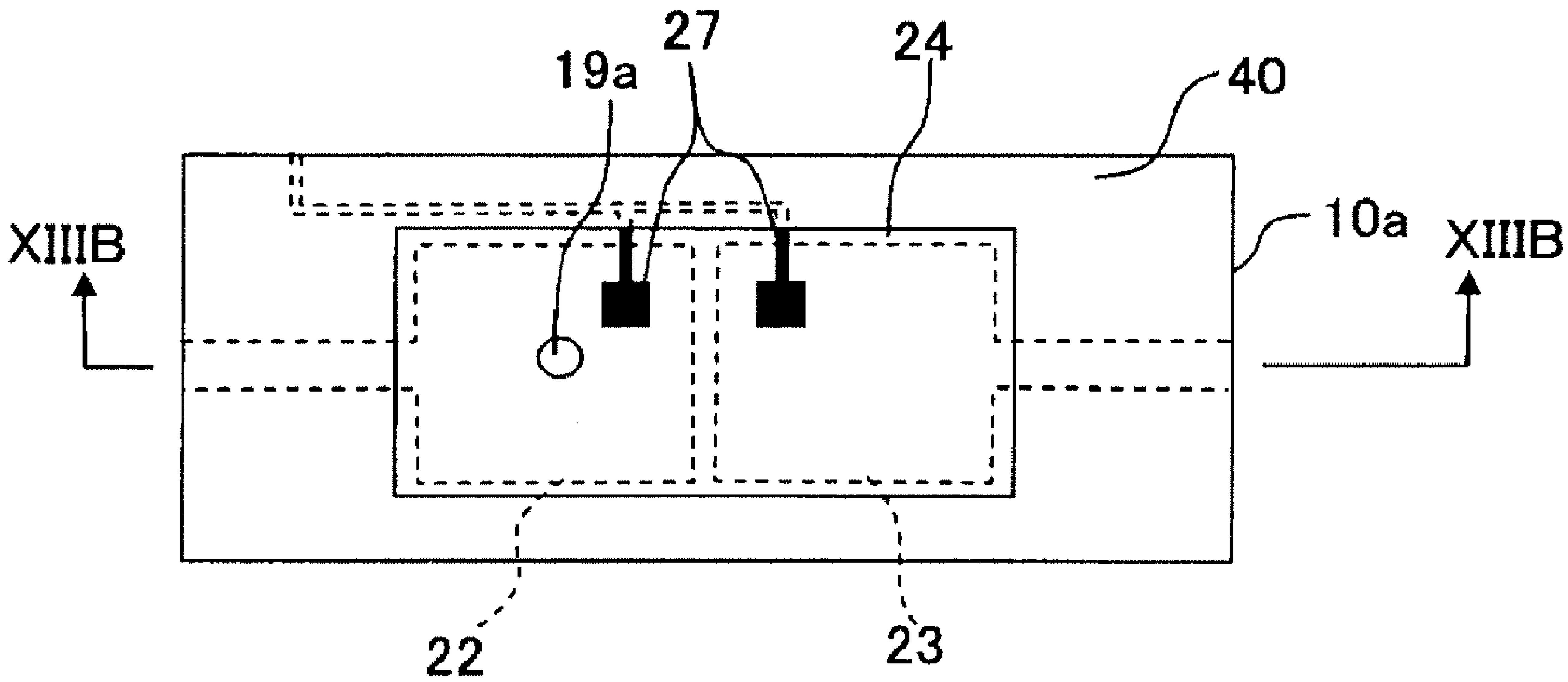


Fig. 13B

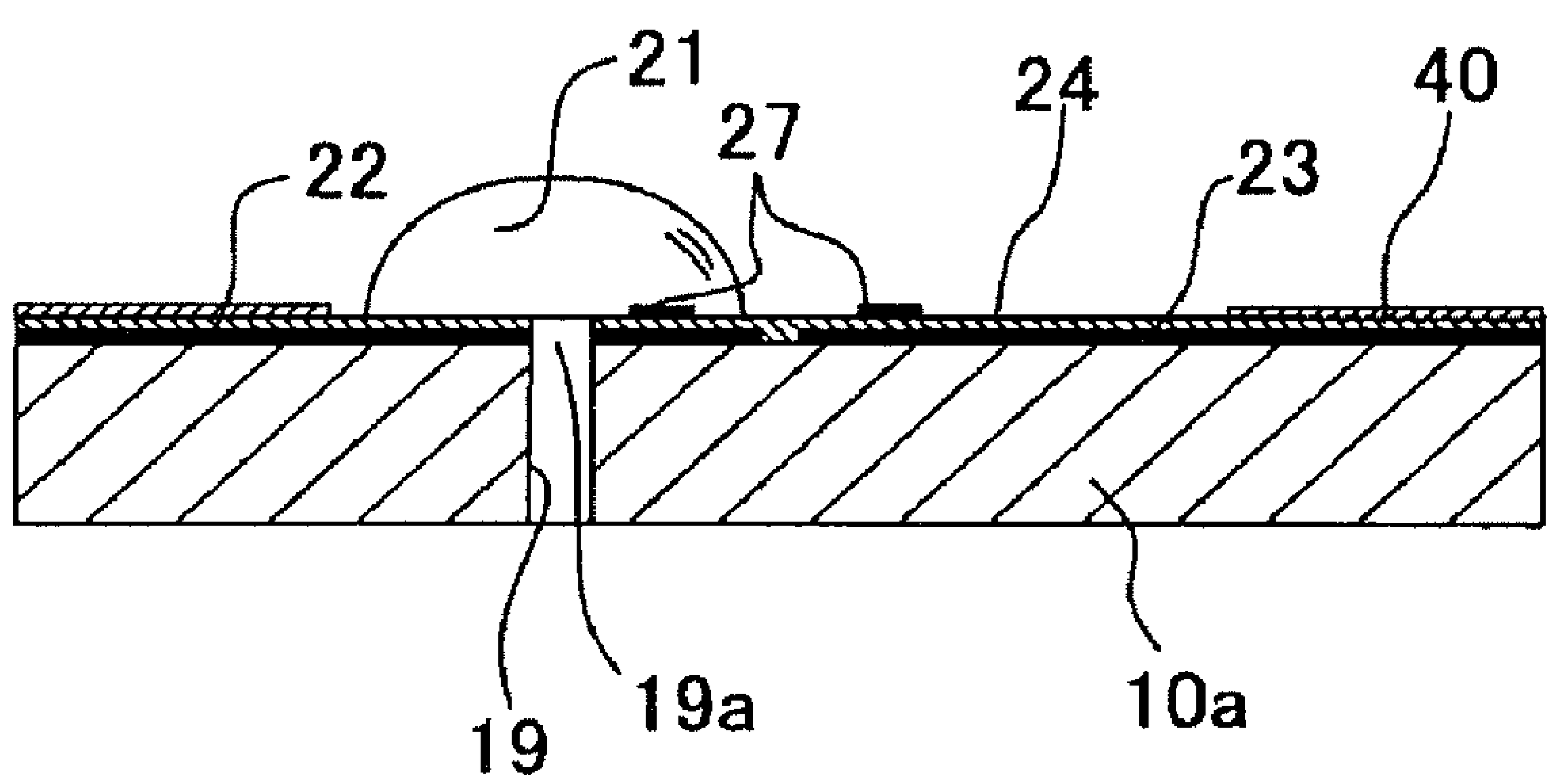


Fig. 14A

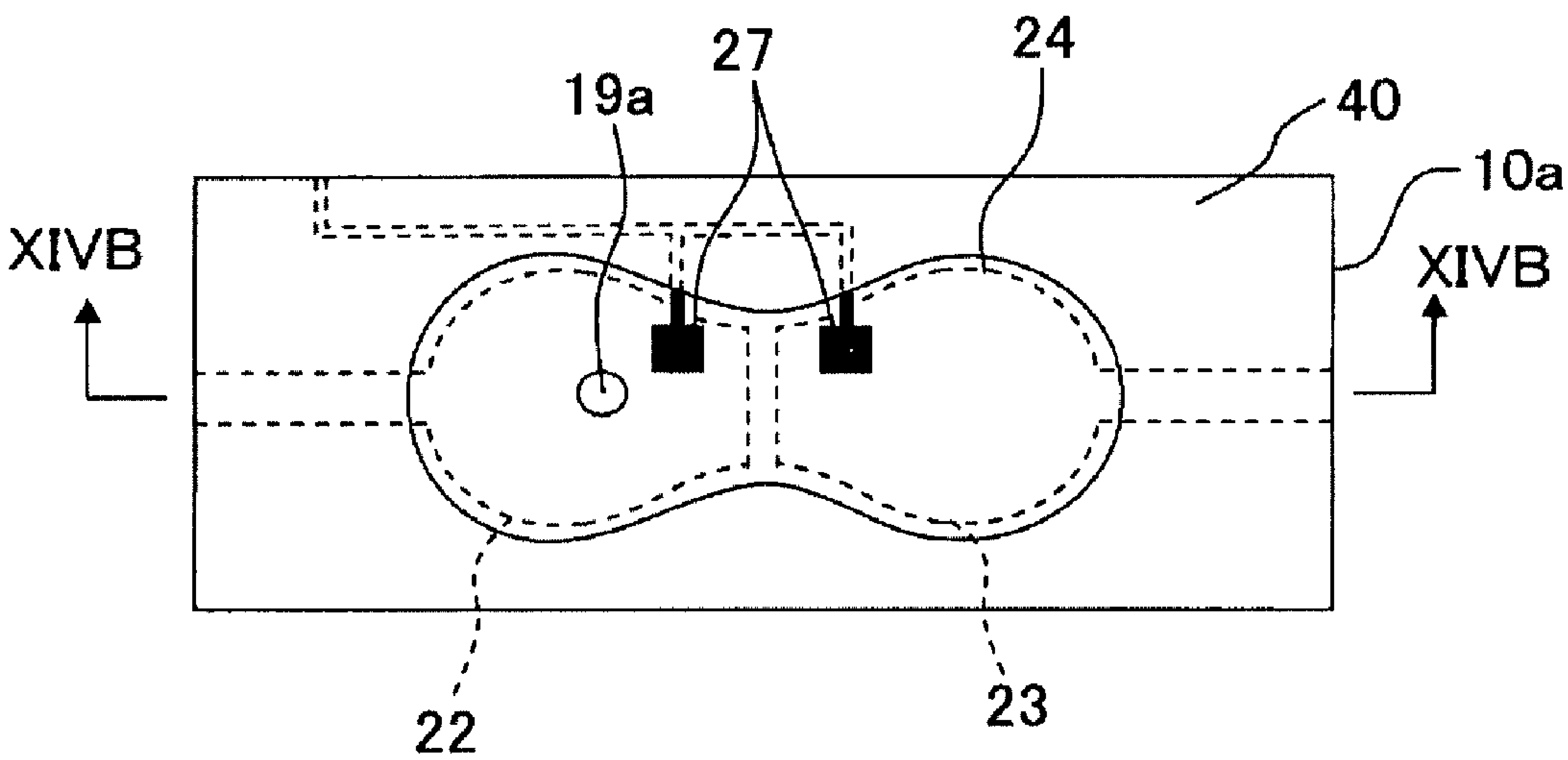


Fig. 14B

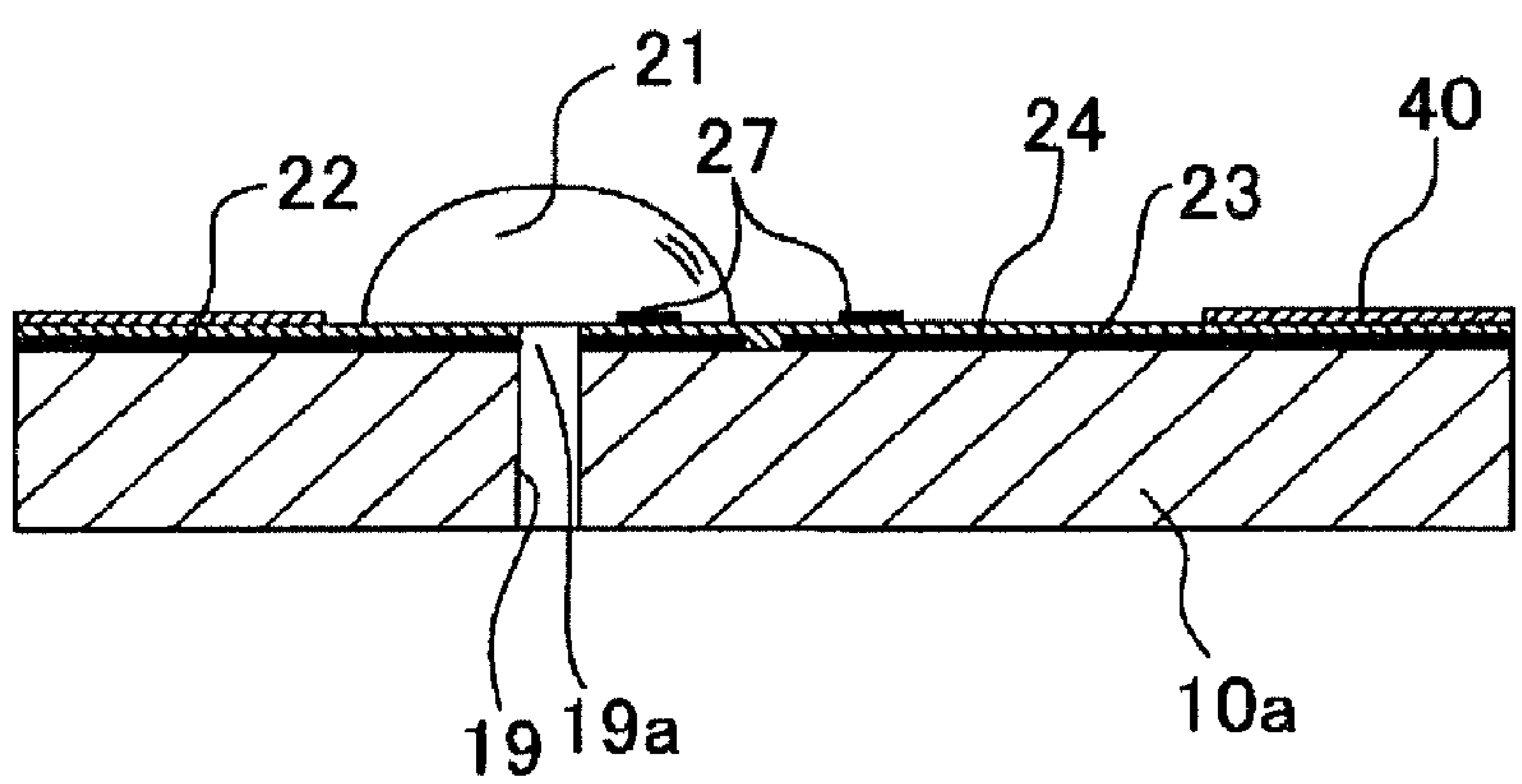


Fig. 15A

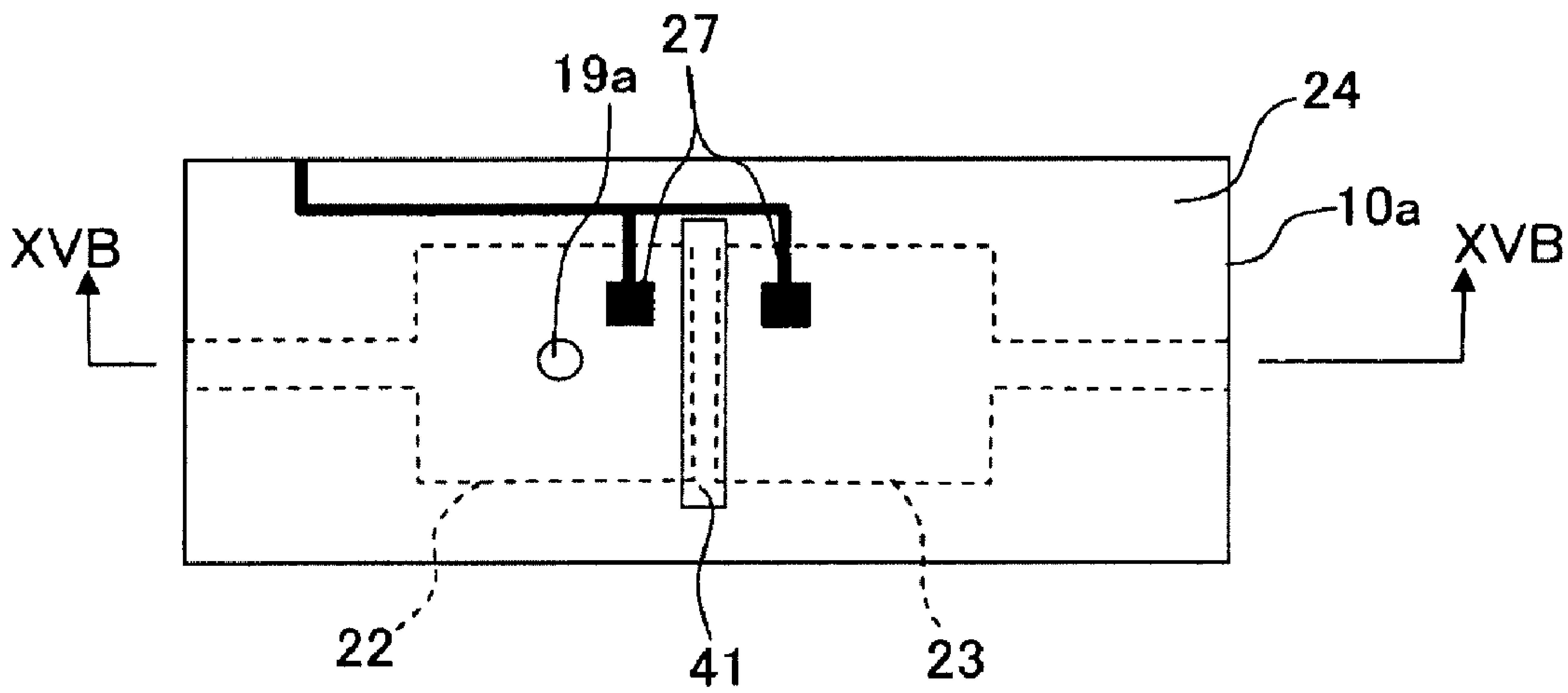


Fig. 15B

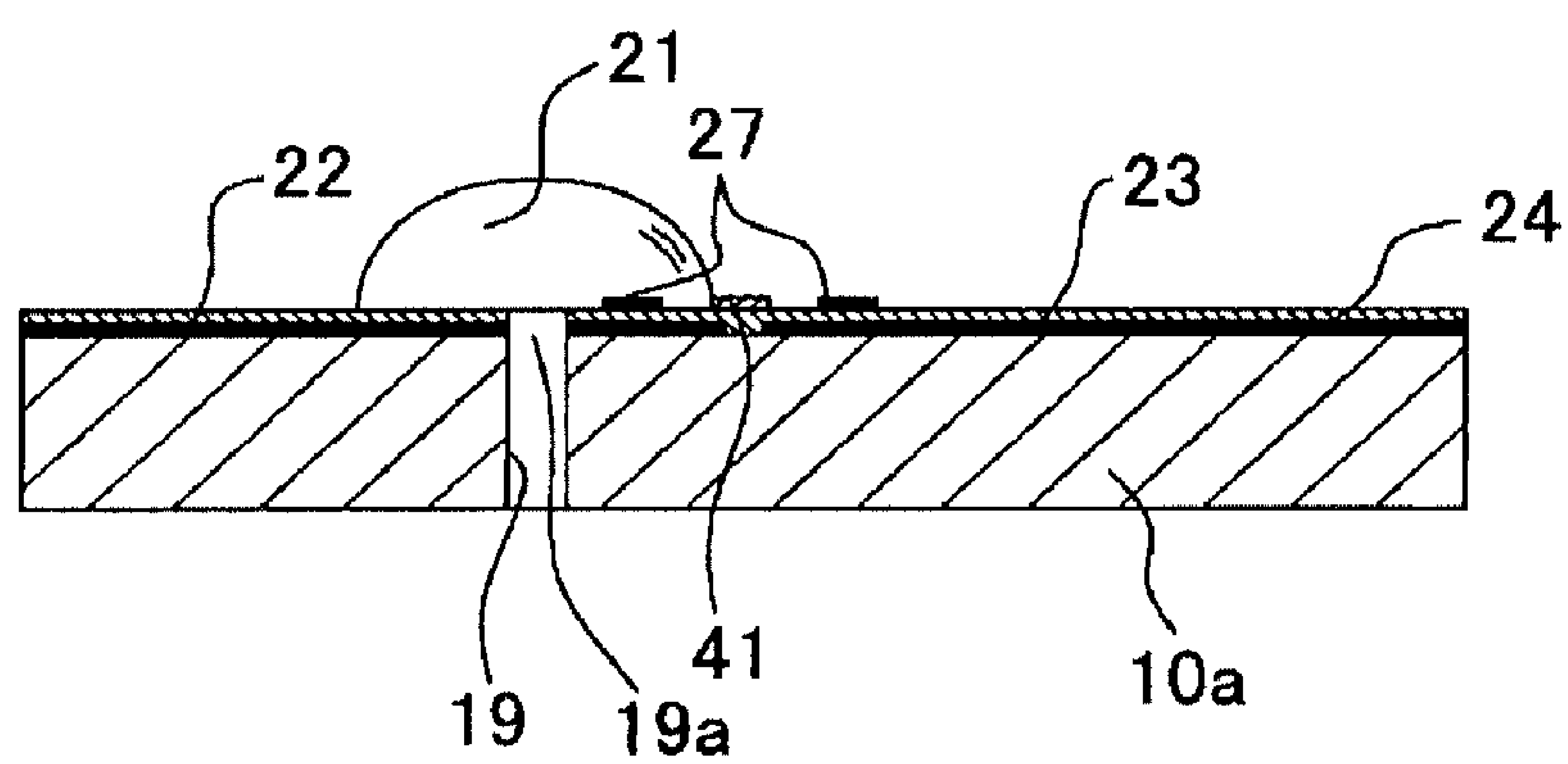


Fig. 16A

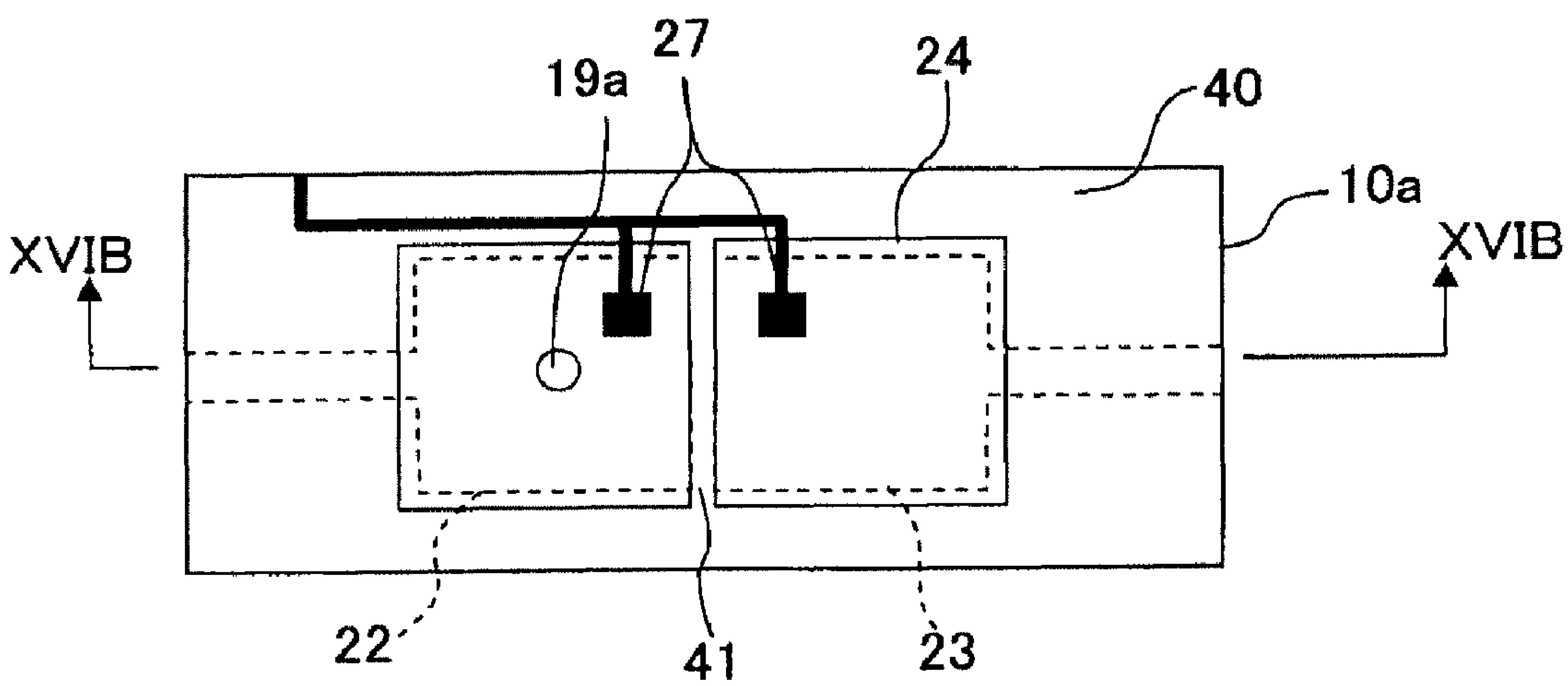


Fig. 16B

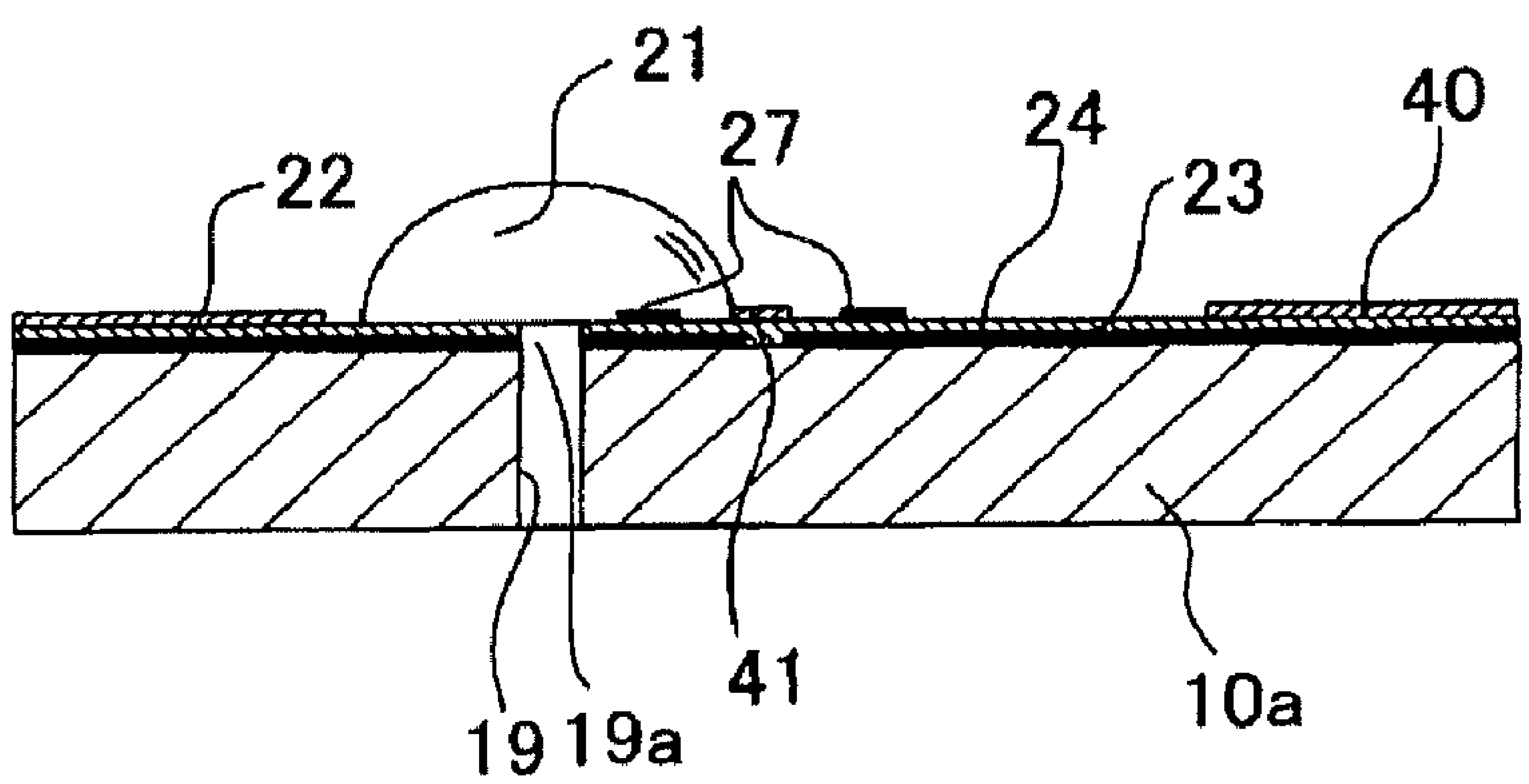


Fig. 17A

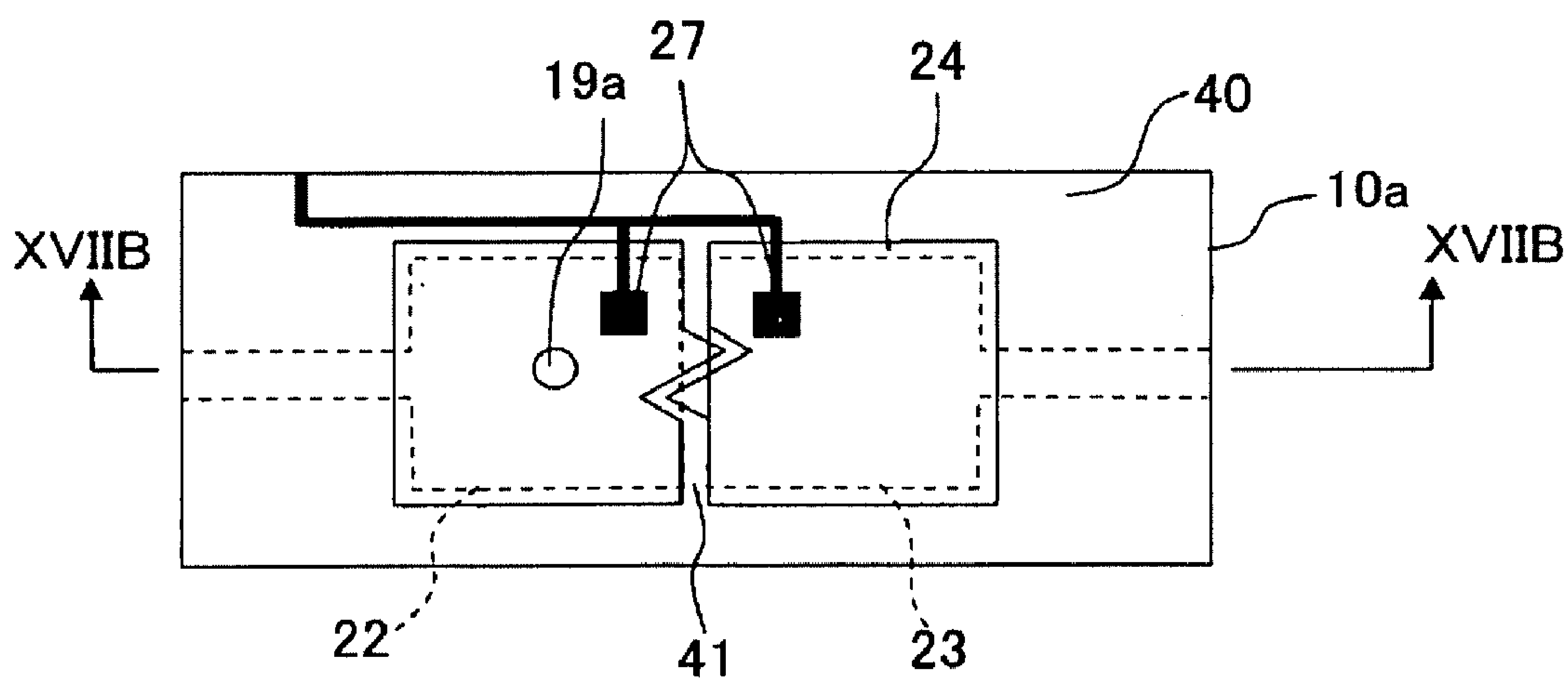


Fig. 17B

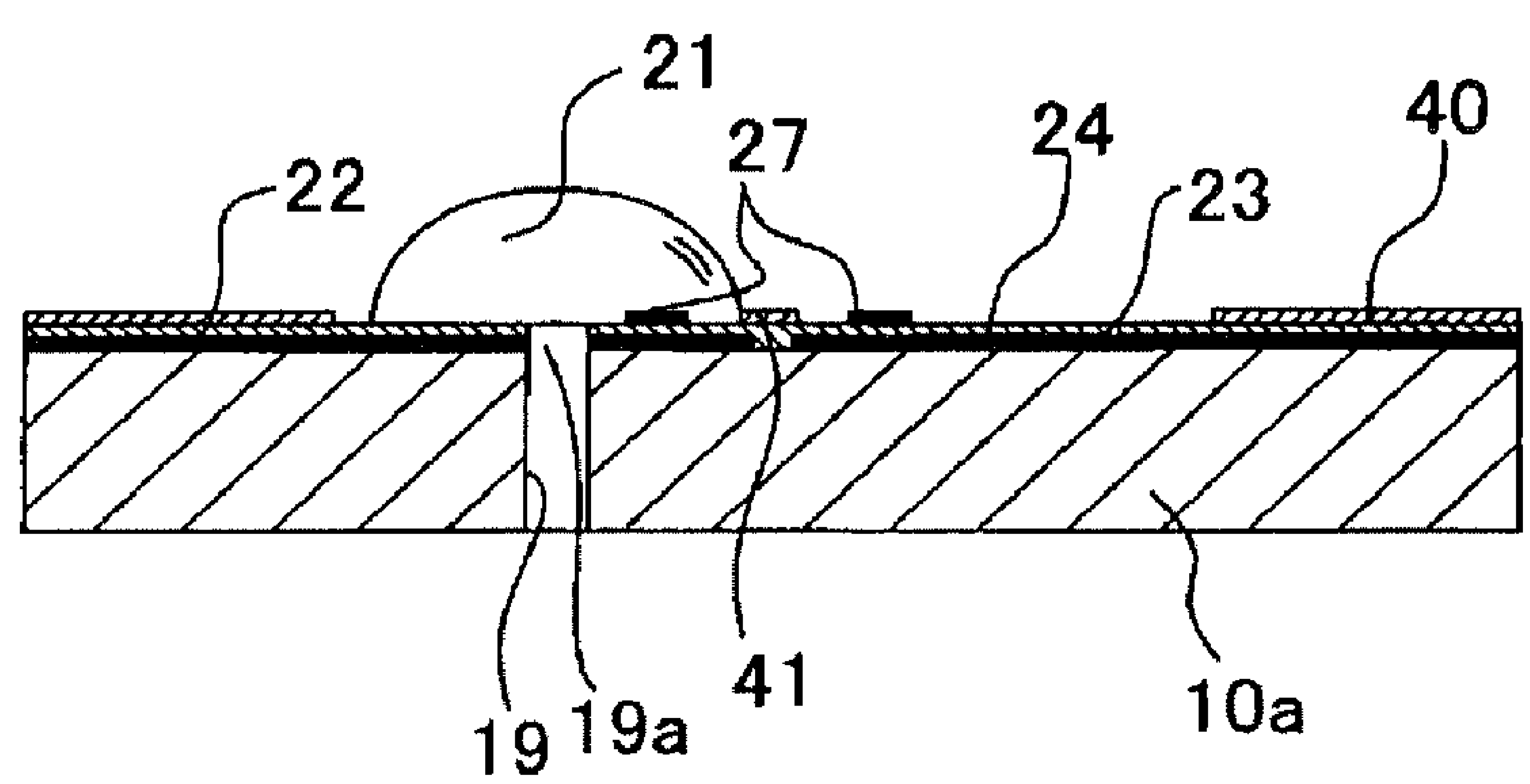
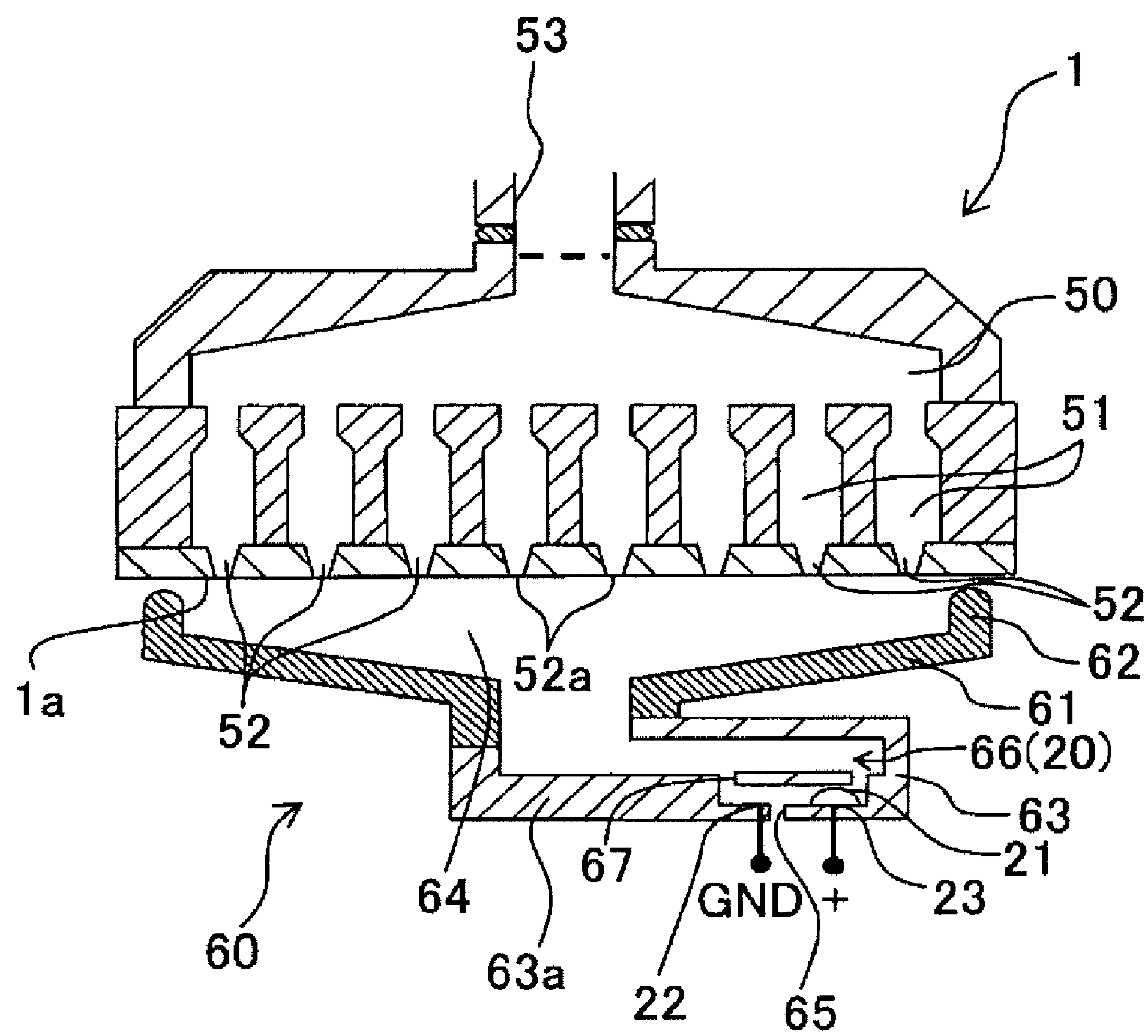


Fig. 18



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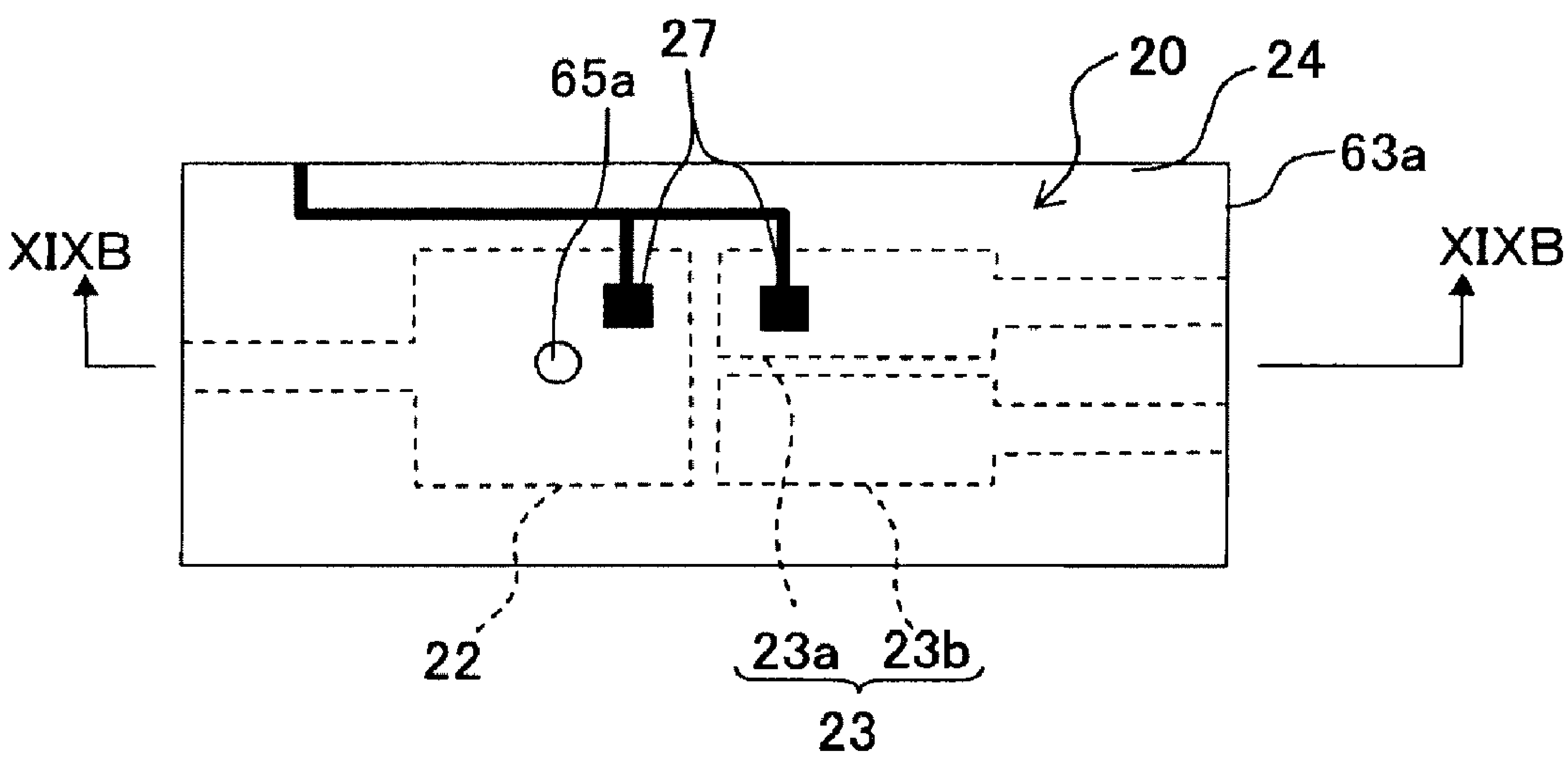


Fig. 19B

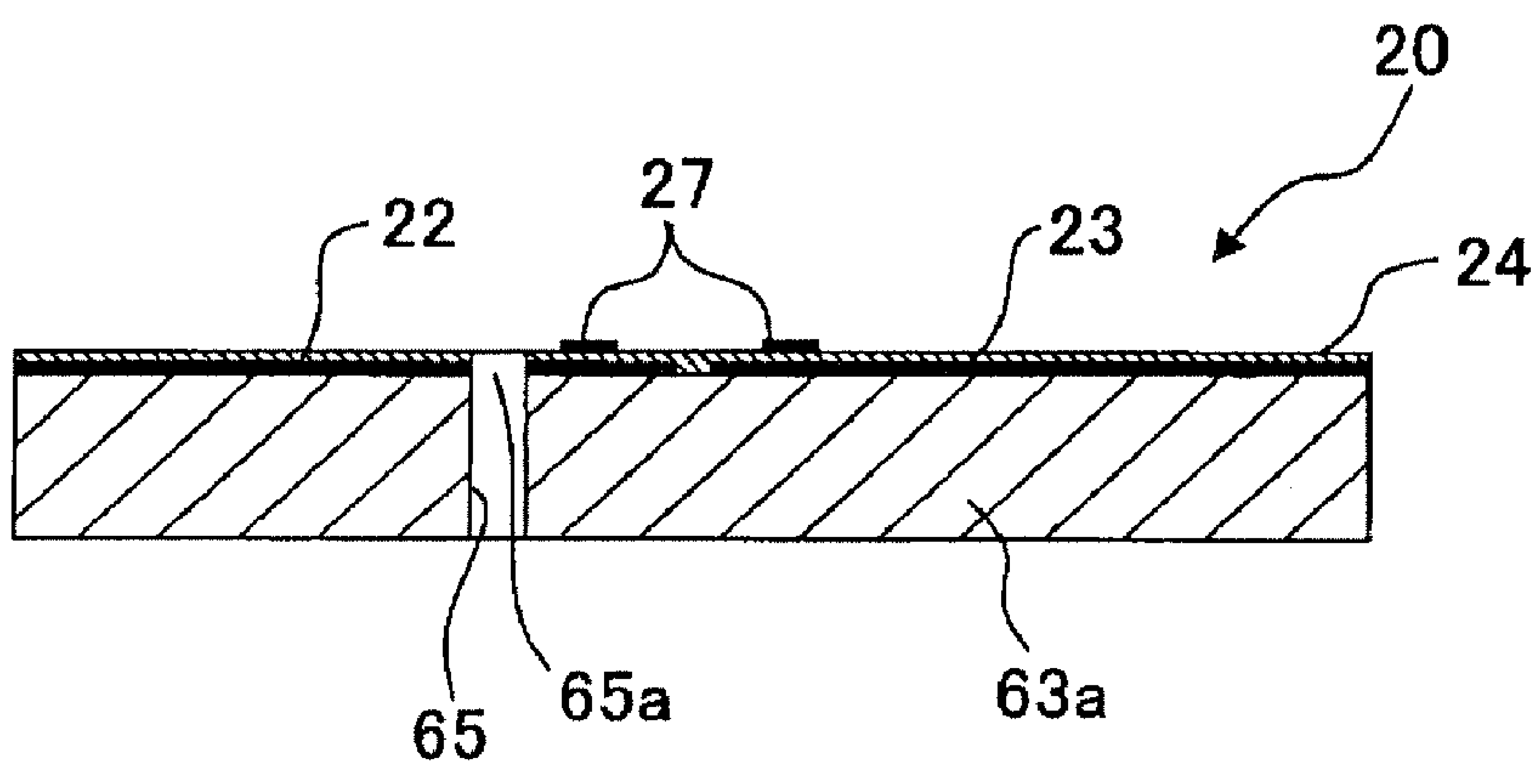
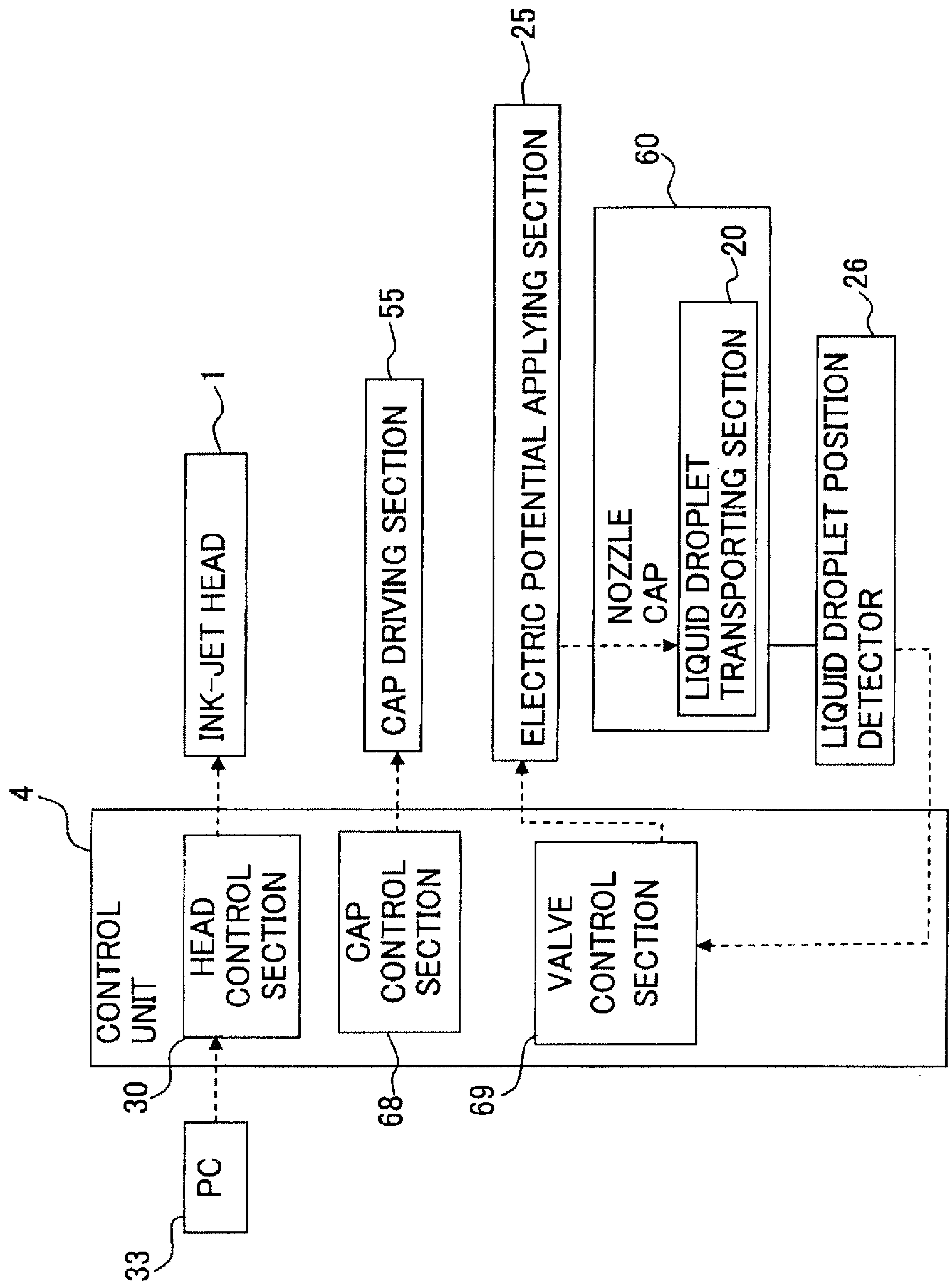


Fig. 20



CONTROL UNIT
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HEAD CONTROL SECTION
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CAP CONTROL SECTION
68
VALVE CONTROL SECTION
69
PC
33
INK-JET HEAD
1
CAP DRIVING SECTION
55
ELECTRIC POTENTIAL APPLYING SECTION
25
NOZZLE CAP
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LIQUID DROPLET TRANSPORTING SECTION
20
LIQUID DROPLET POSITION DETECTOR
26

Fig. 21

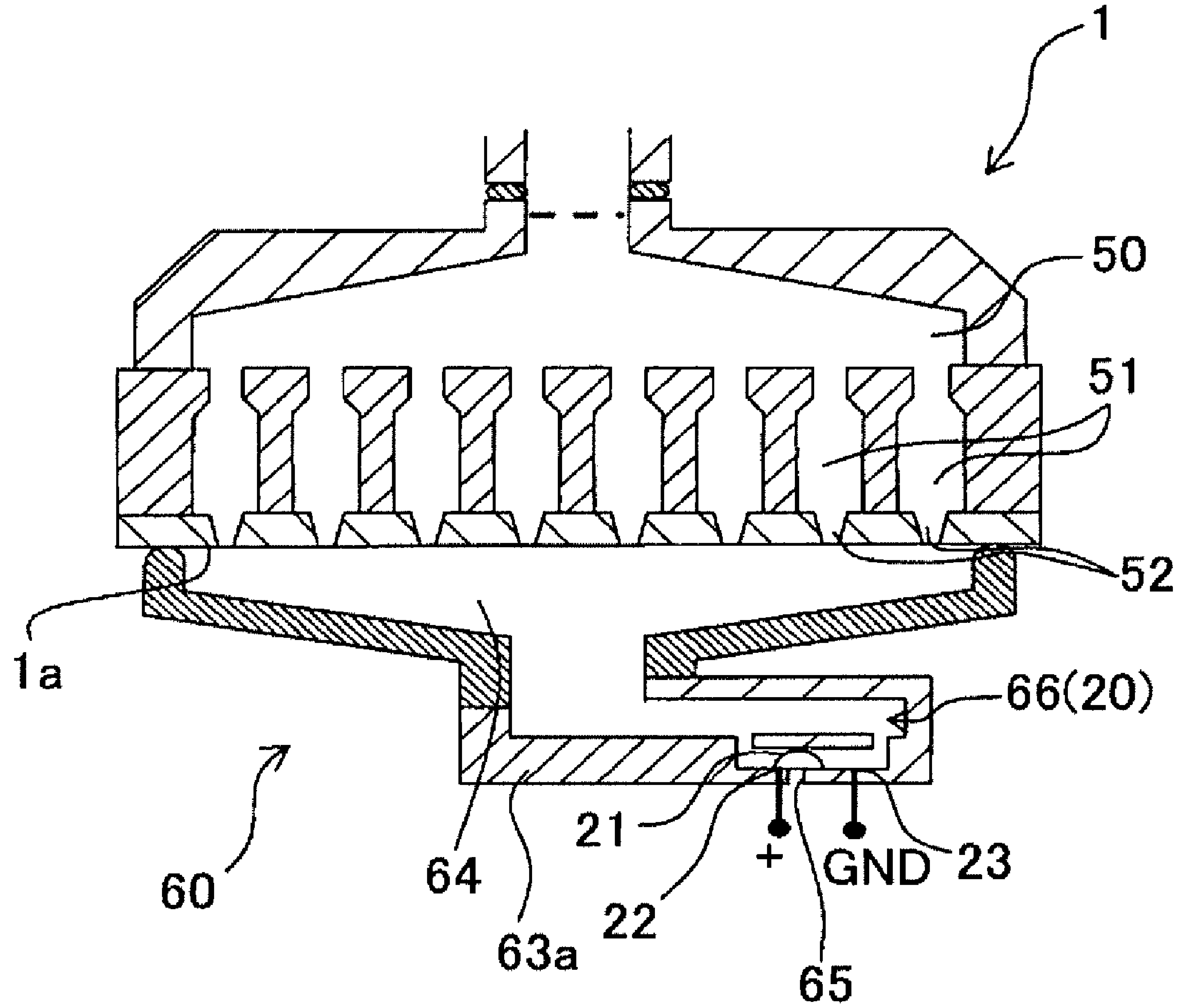


Fig. 22A

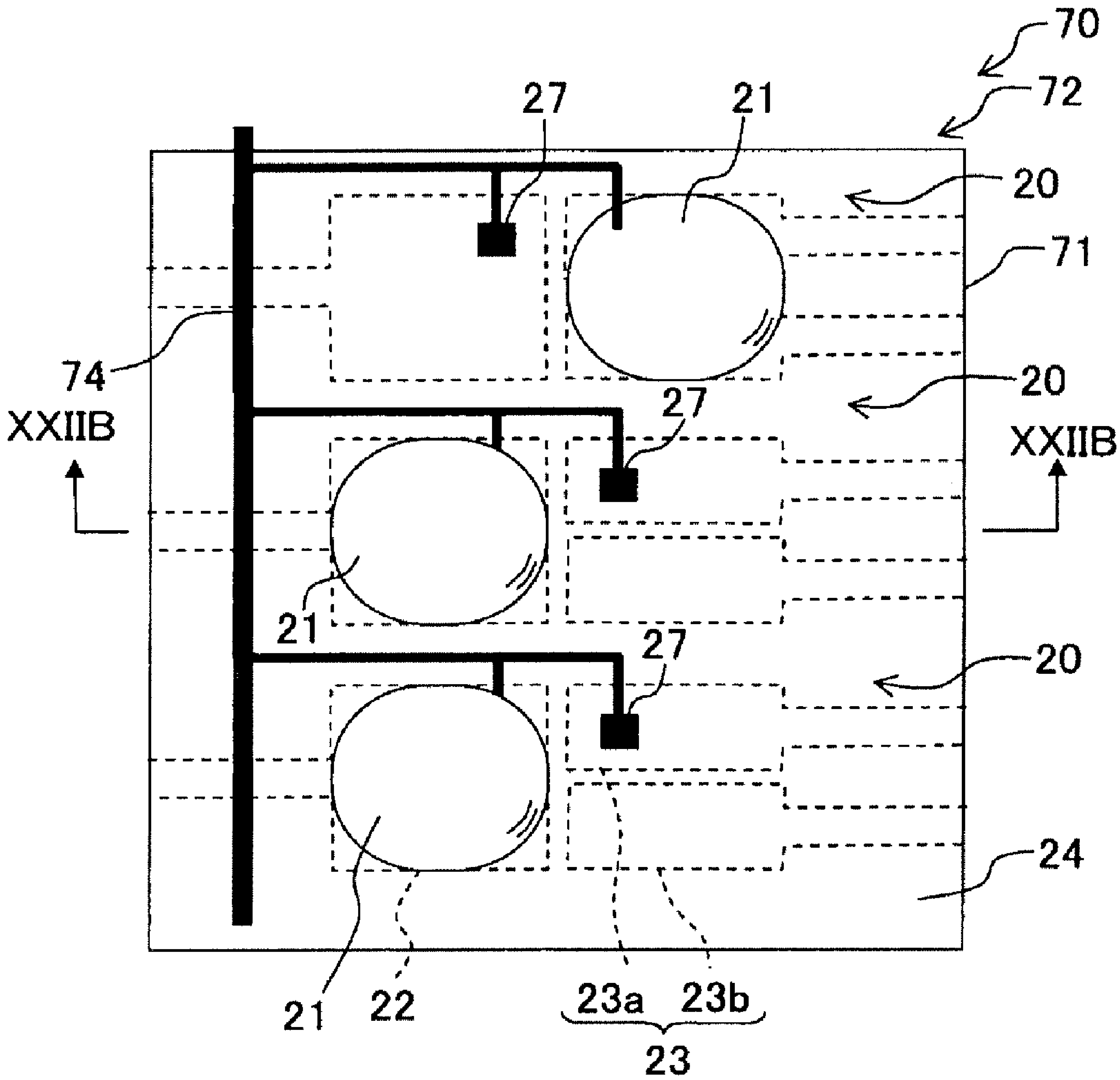


Fig. 22B

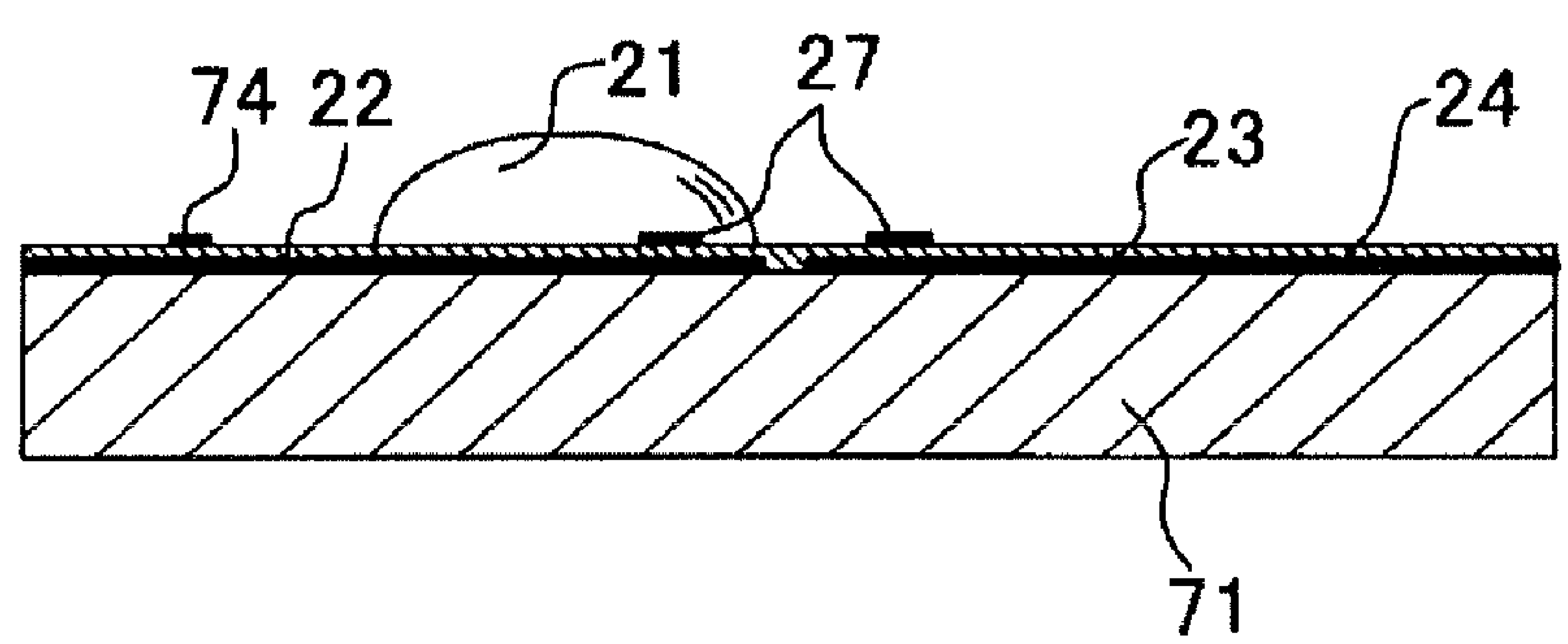
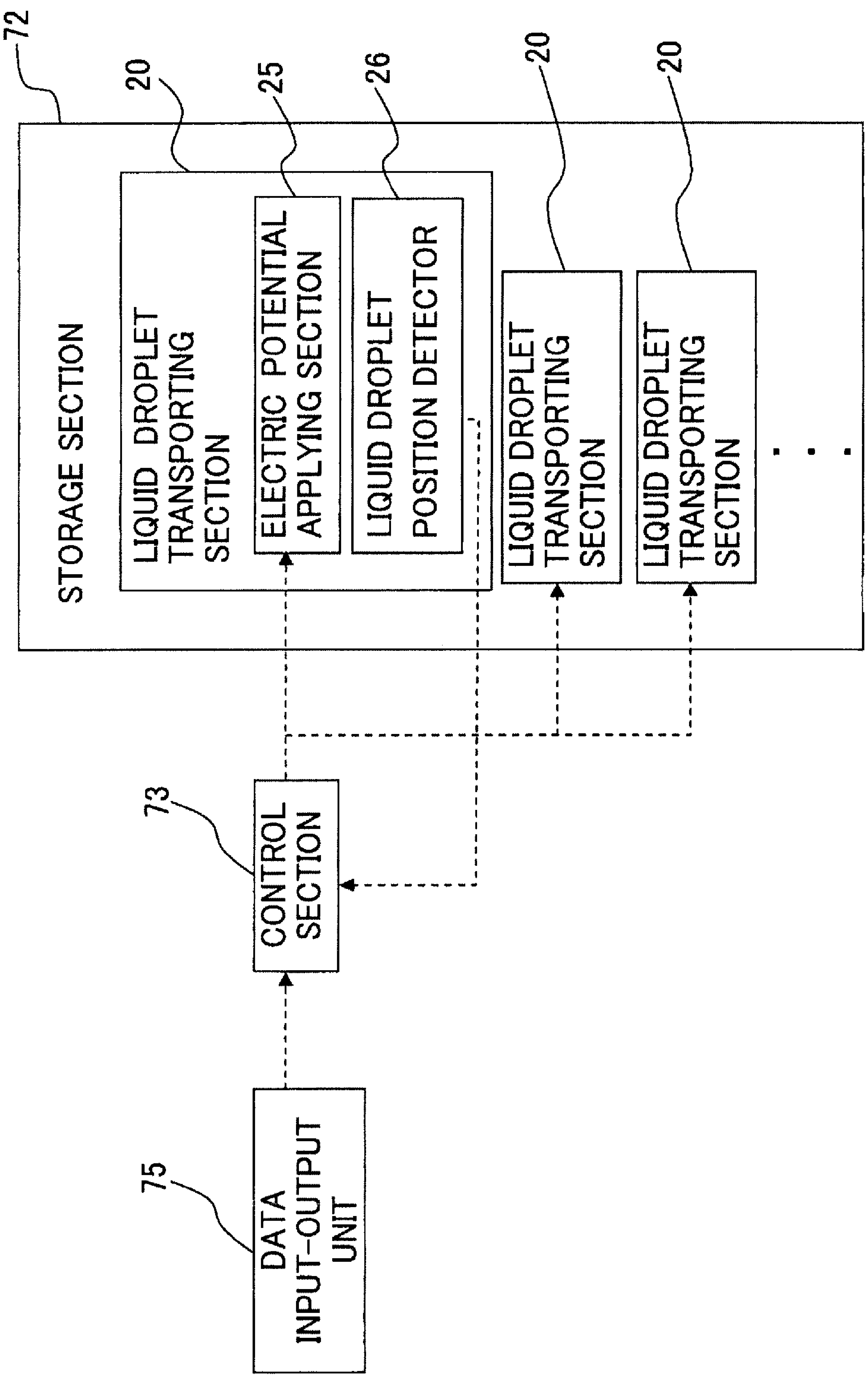


Fig. 23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STORAGE SECTION
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LIQUID DROPLET POSITION DETECTOR
20
LIQUID DROPLET TRANSPORTING SECTION
20
LIQUID DROPLET TRANSPORTING SECTION
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73
CONTROL SECTION
75
DATA INPUT-OUTPUT UNIT

Fig. 24A

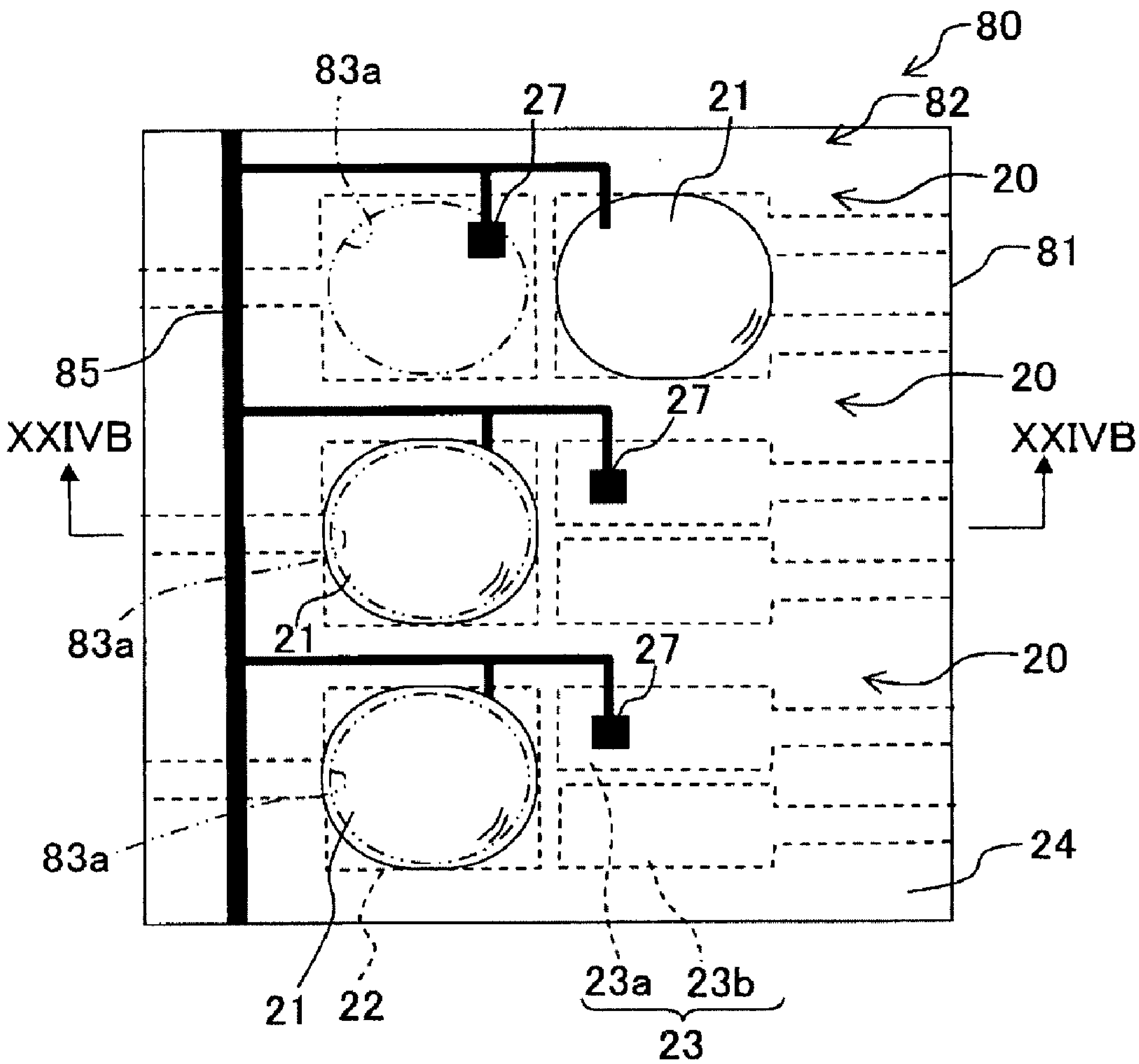


Fig. 24B

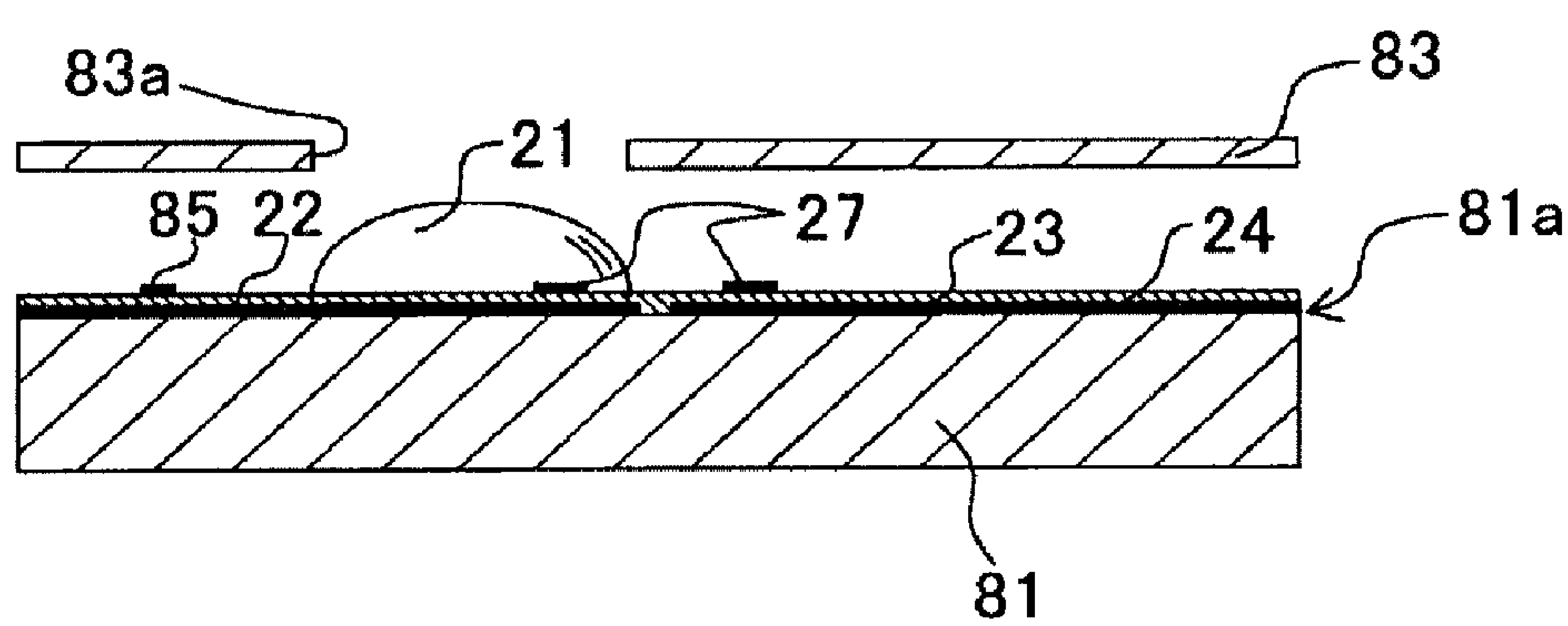
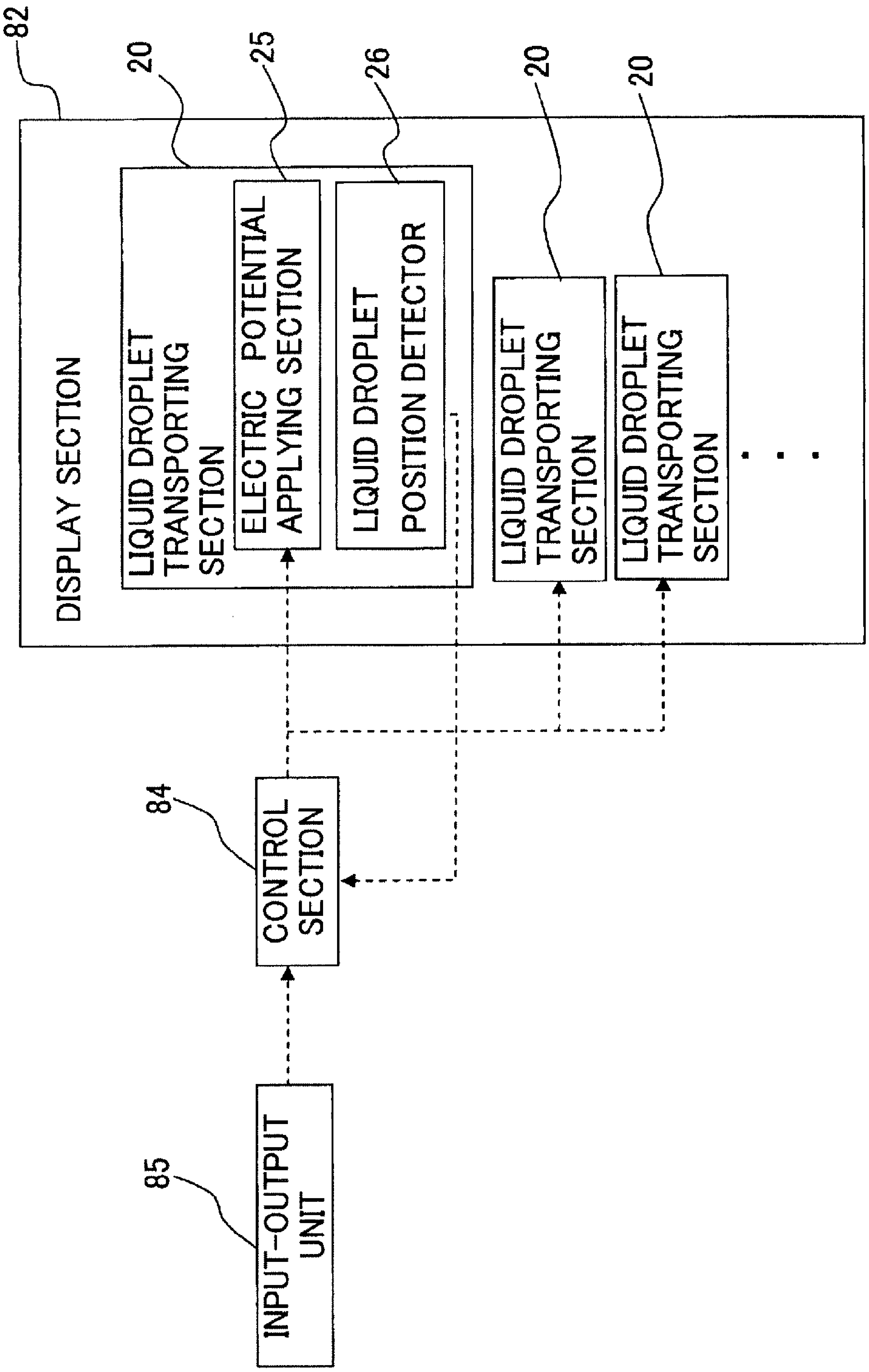


Fig. 25


82
DISPLAY SECTION
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26
LIQUID DROPLET POSITION DETECTOR
20
LIQUID DROPLET TRANSPORTING SECTION
20
LIQUID DROPLET TRANSPORTING SECTION
84
CONTROL SECTION
85
INPUT-OUTPUT UNIT

LIQUID DROPLET TRANSPORTING APPARATUS, AND VALVE, MEMORY, DISPLAY UNIT USING THE LIQUID DROPLET TRANSPORTING APPARATUS

CROSS REFERENCE TO RELATED APPLICATION

The present application is a divisional application of U.S. patent application Ser. No. 11/729,761, filed on Mar. 29, 2007 now U.S. Pat. No. 7,926,914, which claims priority from Japanese Patent Application No. 2006-097263, filed on Mar. 31, 2006, the disclosures of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a liquid droplet transporting apparatus which transports a liquid droplet by using an electrowetting phenomenon, a valve, a memory, and a display unit.

2. Description of the Related Art

A technology of transporting a liquid droplet by using a phenomenon in which a liquid repellent property (wetting angle) on a surface of an insulating layer when an electric potential difference is generated on both sides of the insulating layer is changed (electrowetting phenomenon) has hitherto been known. For example, a micro liquid droplet (very small size liquid droplet) transporting device described in Japanese Patent Application Laid-open No. 2005-257569 includes two electrodes (a first electrode and a second electrode) provided to be isolated on a surface of a substrate, a dielectric film which covers the first electrode, and a hydrophobic (water repellent) film (insulating layer) which covers surfaces of the dielectric film and the second electrode continuously. In this liquid droplet transporting device, when a voltage is applied between the two electrodes with a liquid droplet positioned between the two electrodes while making a contact with both areas at which the two electrodes are arranged, a wetting angle of a surface of the hydrophobic film in the area at which the first electrode is arranged and the dielectric film is formed becomes smaller than a wetting angle of a surface of the hydrophobic film in the area at which the second electrode is arranged and the dielectric film is not formed. Therefore, a difference in the wetting angle becomes a driving force, and the liquid droplet is transported from the second electrode to the first electrode in one direction.

The micro liquid droplet transporting device described in Japanese Patent Application Laid-open No. 2005-257569 moves the liquid droplet from one electrode to the other electrode in one direction. On the other hand, apart from such apparatus, also an apparatus which transports a very micro liquid droplet between two areas in which electrodes are arranged has been desired in various fields. In this case, when it is possible to detect as to which area among the two areas the liquid droplet exists, such an apparatus would be highly applicable markedly.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a liquid droplet transporting apparatus which is capable of transporting a liquid droplet between to areas by using an electrowetting phenomenon, and which is also capable of detecting as to which area among the two areas the liquid droplet exists. It should be noted that parenthesized reference numerals assigned to elements shown below are only examples of the elements, and are not intended to limit the elements.

According to a first aspect of the present invention, there is provided a liquid droplet transporting apparatus including: a first electrode (**22**) which is arranged on a surface (**10***b*) of a substrate (**10***a*); a second electrode (**23**) which is arranged apart from the first electrode on the surface of the substrate, an insulating layer (**24**) which is arranged to cover both the first electrode and the second electrode, and in which a liquid repellent property on a surface thereof changes according to an electric potential difference between the first and second electrodes (the first electrode **22** or the second electrode **23**) and an electroconductive liquid droplet (**21**) on the surface; and a third electrode (**23***b*) which cooperates with the second electrode to detect a presence of the liquid droplet on the second electrode.

According to the liquid droplet transporting apparatus of the present invention, by making the electric potential of the first electrode and the electric potential of the second electrode to be different, it is possible to change the liquid repellent property (wetting angle) on the surface of the insulating layer covering the first electrode and the second electrode. Consequently, it is possible to transport the liquid droplet between an area at which the first electrode is arranged and an area at which the second electrode is arranged, from an area of a higher liquid repellent property to an area of a lower liquid repellent property. In other words, it is possible to transport the liquid droplet between the two areas by a simple structure made of the two electrodes (first electrode and the second electrode) and the insulating layer. In the present invention, the "area at which the first electrode is arranged" means an area of the insulating layer, overlapping with the first electrode, and the "area at which the second electrode is arranged" means an area of the insulating layer, overlapping with the second electrode.

Furthermore, since the third electrode is provided which cooperates with the second electrode to detect the presence of the liquid droplet on the second electrode, when the electroconductive liquid droplet exists on the second electrode, it is possible to detect a predetermined electrostatic capacitance between the second electrode and the third electrode. On the other hand, when the electroconductive liquid droplet does not exist on the second electrode, a detected value of the electrostatic capacitance between the second electrode and the third electrode is less than the predetermined value (of the electrostatic capacitance). Consequently, by detecting the electrostatic capacitance between the second electrode and the third electrode, it is possible to judge whether or not the liquid droplet exists on the second electrode. As a result of this, it is possible to detect whether the liquid droplet exists on the area at which the first electrode is arranged or on the area at which the second electrode is arranged.

In the liquid droplet transporting apparatus (**20**) of the present invention, at least one of the first electrode (**22**) and the second electrode (**23**) may be divided as (into) at least two split electrodes (**23***a* and **23***b*) which are arranged to be mutually isolated, on the surface (**10***b*) of the substrate (**10***a*). In this case, when the electroconductive liquid droplet exists on the two split electrodes, it is possible to detect a predetermined electrostatic capacitance between the two split electrodes. On the other hand, when the electroconductive liquid droplet does not exist on the two split electrodes, the electrostatic capacitance between the two split electrodes is declined. Consequently, according to a possibility of detecting or not detecting the electrostatic capacitance between the two split electrodes, it is possible to judge (determine) whether or not the liquid droplet exists on the two split electrodes. In this case, one of the split electrodes may be the third electrode (**23***b*).

The liquid droplet transporting apparatus (**20**) of the present invention may further include an electric-potential applying mechanism (**25**) which applies an electric potential to each of the first electrode (**22**) and the second electrode (**23**). The liquid droplet may be transported in the insulating layer (**24**) between portions thereof covering the first electrode and the second electrode respectively, by applying different electric potential to the first electrode and the second electrode respectively with the electric potential applying mechanism to reduce a liquid repellent property on the surface of the insulating layer at a portion among the portions covering one of the first and second electrodes to be lower than a liquid repellent property of another portion covering the other of the first and second electrodes. In this case, it is possible to transport the liquid droplet between the area at which the first electrode is formed and the area at which the second electrode is formed, by applying the different electric potential to each of the first electrode and the second electrode to reduce the liquid repellent property on the surface of the part of the insulating layer covering one electrode to be lower than the liquid repellent property of the portion of the insulating layer covering the other electrode.

In the liquid droplet transporting apparatus (**20**) of the present invention, the split electrodes (**23***a* and **23***b*) may be arranged such that when the liquid droplet (**21**) is transported to an area in which the split electrodes are arranged, the liquid droplet is positioned between the split electrodes while making a contact with both of the split electrodes, and the liquid droplet transporting apparatus (**20**) may further include a liquid droplet position detector (**26**) which detects whether the liquid droplet exists on an area at which the first electrode is arranged or on an area at which the second electrode is arranged, based on an electrostatic capacitance between the split electrodes. In this case, when the electroconductive liquid droplet exists between the two split electrodes while making a contact with both the split electrodes, an electrostatic capacitance is generated between the two split electrodes and the liquid droplet, with the insulating layer sandwiched between the two split electrodes and the liquid droplet, and when the liquid droplet does not exist, the electrostatic capacitance is decreased. Therefore, by detecting the electrostatic capacitance between the two split electrodes, it is possible to detect whether the liquid droplet exists on the area at which the first electrode is arranged or on the area at which the second electrode is arranged.

In the liquid droplet transporting apparatus (**20**) of the present invention, ground electrodes (**27**) may be arranged on the surface (**24***c*) of the insulating layer (**24**) at portions thereof covering the first electrode (**22**) and the second electrode (**23**) respectively. In this case, by keeping the liquid droplet in contact with the ground electrode (**27**) and maintaining a predetermined electric potential, an electric potential difference between the electrode and the liquid droplet is stabilized. Consequently, it is possible to transport the liquid droplet assuredly.

In the liquid droplet transporting apparatus (**20**) of the present invention, the third electrode (**124**) may be isolated from the surface (**10***b*) of the substrate (**10**), and may extend to face the second electrode (**123**). By arranging the third electrode in such manner, when the liquid droplet exists on the second electrode, it is possible to detect the electrostatic capacitance between the second electrode and the third electrode. On the other hand, when the liquid droplet does not exist on the second electrode, the electrostatic capacitance which is detected is declined. Consequently, by measuring the electrostatic capacitance, it is possible to detect whether the liquid droplet exists on the area at which the first electrode is arranged or on the area at which the second electrode is arranged.

In the liquid droplet transporting apparatus (**20**) of the present invention, the third electrode (**224**) may extend to face the second electrode (**123**) and a part of the first electrode, and may be arranged as a ground electrode. In this case, even when the liquid droplet exists on the first electrode, or when the liquid droplet exists on the second electrode, the liquid droplet is always in contact with the third electrode, and is kept at a predetermined electric potential. Consequently, since the electric potential between the electrode and the liquid droplet is stable, it is possible to transport the liquid droplet assuredly. Furthermore, when the liquid droplet exists on the second electrode, it is possible to detect the electrostatic capacitance between the second electrode and the third electrode. On the other hand, when the liquid droplet does not exist on the second electrode, it is not possible to detect the predetermined electrostatic capacitance. Consequently, by measuring the electrostatic capacitance, it is possible to detect whether the liquid droplet exists on the area at which the first electrode is arranged or on the area at which the second electrode is arranged.

In the liquid droplet transporting apparatus (**20**) of the present invention, a first liquid repellent film (**40**) which always has a liquid repellent property not less than the liquid repellent property of the insulating layer (**24**) may be formed on the surface (**10***b*) of the substrate (**10***a*) at an area outside the first electrode (**22**) and the second electrode (**23**). In this case, it is possible to prevent the liquid droplet from moving abruptly out of a range of the electrodes, due to vibration of the liquid droplet, or the like. A liquid repellent property of the area outside the first electrode and the second electrode may be higher than the liquid repellent property of the insulating layer. In this case, the insulating layer covering the first electrode and the second electrode may extend up to the outer side of the first electrode and the second electrode, and form the first liquid repellent film, or the first liquid repellent film may be formed to be separate from the insulating layer, on the outer side of the first electrode and the second electrode.

In the liquid droplet transporting apparatus (**20**) of the present invention, between the first electrode (**22**) and the second electrode (**23**), a width of an area in which the first liquid repellent film (**40**) is absent may be locally narrowed. In this case, it is possible to prevent the liquid droplet from moving abruptly to an electrode on an opposite side, due to vibration of the liquid droplet, or the like.

In the liquid droplet transporting apparatus (**20**) of the present invention, a second liquid repellent film (**41**) which always has a liquid repellent property not less than the liquid repellent property of the insulating layer (**24**) may be formed in an area on the surface (**10***b*) of the substrate (**10***a*) at an area between the first electrode (**22**) and the second electrode (**23**). In this case, it is possible to prevent the liquid droplet from moving abruptly to the electrode on the opposite side, due to the vibration of the liquid droplet, or the like. Moreover, a liquid repellent property of the area between the first electrode and the second electrode may be higher than the liquid repellent property of the insulating film, and the second liquid repellent film may be formed between the first electrode and the second electrode by the insulating layer covering the first electrode and the second electrode, or the second liquid repellent may be formed to be separate from the insulating layer, between the first electrode and the second electrode.

In the liquid droplet transporting apparatus (**20**) of the present invention, a part of the second liquid repellent film (**41**) may be projected toward an area in which each of the first electrode and the second electrode is arranged. In this case, it is possible to transport the liquid droplet smoothly between the two areas at which the electrodes (the first electrode and the second electrode) are arranged, while preventing the liquid droplet from moving abruptly to the opposite side, due to the vibration of the liquid droplet, or the like.

The liquid droplet transporting apparatus (**20**) of the present invention may be provided to a valve (**11**). In the valve which includes the liquid droplet transporting apparatus of the present invention, a fluid passage (**19**) which has opening (**19***a*) in an area at which the first electrode (**22**) is arranged, may be formed in the substrate (**10***a*), the opening of the fluid passage may be closed by the liquid droplet (**21**) when the liquid droplet (**21**) exists in the area at which the first electrode is arranged, and the opening of the fluid passage may be opened when the liquid droplet exists in an area at which the second electrode (**23**) is arranged. In this case, it is possible to close the opening of the fluid passage by transporting the liquid droplet in the area at which the first electrode is arranged, and to open the opening of the fluid passage by transporting the liquid droplet to the area at which the second electrode is arranged. In other words, since the valve includes the liquid droplet transporting apparatus having a simple structure including the two electrodes and the insulating layer, it is possible to open and close the fluid passage.

The valve (**11**) including the liquid droplet transporting apparatus (**20**) of the present invention may be provided on an ink cartridge (**5**) including an ink accommodating space (**12**) which accommodates an ink (I), and an atmosphere-communication passage (**19**) which communicates the ink accommodating space (**12**) and an atmosphere. The atmosphere-communication passage may be opened and closed by transporting the liquid droplet (**21**) between the first electrode (**22**) and the second electrode (**23**). In this case, the atmosphere-communication passage is closed by transporting the liquid droplet to the first electrode when the ink is not supplied from the ink cartridge to a destination of supply, and the atmosphere-communication passage is opened by transporting the liquid droplet to the second electrode only when the ink is supplied. In other words, by (using) the liquid droplet transporting apparatus having a simple structure, it is possible to prevent effectively, the drying (thickening) of ink without causing an insufficiency of ink supply.

The valve (**11**) including the liquid droplet transporting apparatus (**20**) of the present invention may be provided on a cap (**60**) which covers an ink jetting surface (**1***a*) of an ink-jet head (**1**) which jets the ink (I) on to a recording medium (P), and which includes a communication passage (**65**) which communicates with a space (**64**) defined by the ink jetting surface and the cap, and an outside of the cap, and the communication passage may be opened and closed by transporting the liquid droplet (**21**) between the first electrode (**22**) and the second electrode (**23**). With the cap mounted on the ink jetting surface of the ink jetting head, it is possible to prevent the drying of the ink by closing the communication passage of the cap by positioning the liquid droplet on the first electrode. On the other hand, at the time of putting and taking the cap on and off the ink jetting surface, it is possible to prevent a meniscus of a nozzle from being destroyed due to a pressure fluctuation in the space in the cap at the time of putting the cap on, by opening the communication passage by transporting the liquid droplet to the second electrode. In this manner, by (using) the liquid droplet transporting apparatus having a simple structure, it is possible to prevent the drying of the ink and the destruction of the meniscus.

The liquid droplet transporting apparatus (**20**) of the present invention may be provided to a memory (**70**). In the memory including the liquid droplet transporting apparatus of the present invention, the liquid droplet transporting apparatus may transport the liquid droplet (**21**) between the first electrode (**22**) and the second electrode (**23**) according to data to be stored in the memory. In this case, it is possible to transport the liquid droplet to any of an area at which the first electrode is arranged and an area at which the second electrode is arranged, according to the data to be stored in the memory. In other words, since the memory includes the liquid droplet transporting apparatus having a simple structure, it is possible to store a data of 1 bit. Moreover, since it is possible to detect whether the liquid droplet exists on the area at which the first electrode is arranged or on the area at which the second electrode is arranged, it is possible to distinguish and read the data which is stored. Furthermore, in the memory of the present invention, since a silicon substrate which is used in a normal semiconductor memory is not necessary (indispensable), it is possible to manufacture the memory at a low cost by using a substrate made of a material such as a synthetic resin.

In the display unit including a liquid droplet transporting apparatus (**20**) of the present invention, a cover plate (**83**) which is arranged to face the surface (**81***a*) of the substrate (**81**), and which has a through hole (**83***a*) which is formed at a position corresponding to the first electrode (**22**), the liquid droplet (**21**) may be a colored liquid, and the liquid droplet transporting apparatus may transport the liquid droplet between the first electrode and the second electrode (**23**) according to data displayed on the display unit. In this case, when the colored liquid droplet is transported to a position on the first electrode, the color of the liquid droplet is displayed upon being transmitted through the cover plate. On the other hand, when the liquid droplet is transported to a position on the second electrode, the color of the liquid droplet is blocked by the cover plate, and is not displayed. Consequently, it is possible to display desired characters, images, and the like by using the liquid droplet transporting apparatus having a simple structure. Moreover, in the display unit in which the liquid droplet transporting apparatus of the present invention is used, the liquid droplet is not moved from the position on the first electrode or the position on the second electrode, unless the electric potential applied to the first electrode and the electric potential applied to the second electrode are different. In other words, it is not necessary to supply an electric power all the time for maintaining the same display state. Consequently, it is possible to maintain the same display state without consuming the electric power.

In a display unit (**80**) including a liquid droplet transporting apparatus (**20**) of the present invention, the first electrode (**22**), a portion of the substrate (**81**) corresponding to the first electrode, and a portion of the insulating layer (**24**) corresponding to the first electrode may be all transparent, and at least one of a second electrode (**23**), a portion of the substrate corresponding to the second electrode, and a portion of the insulating layer corresponding to the second electrode may be non-transparent. In this case, since the first electrode, and the insulating layer and the substrate corresponding to the first electrode are transparent, when a colored liquid droplet is transported to an area at which the first electrode is arranged, a color of the liquid droplet is displayed. On the other hand, since at least one of the second electrode, and the second electrode and the substrate corresponding to the insulating layer is non-transparent (property which does not allow the light to pass through), when a colored liquid droplet is transported to an area at which the second electrode is arranged, the color of the liquid droplet is not displayed when viewed from a surface of the substrate on a side opposite to the electrode. Consequently, by transporting a colored droplet between a position of the first electrode and a position of the second electrode, it is possible to display desired characters, images, and the like.

According to a second aspect of the present invention, there is provided a valve (**11**) including: a substrate (**10***a*) having a fluid passage (**19**) which has an opening (**19***a*) on a surface (**10***b*) of the substrate; a first electrode (**22**) which is arranged on the surface of the substrate, at an area including the opening of the fluid passage; a second electrode (**23**) which is arranged apart from the first electrode on the surface of the substrate; and an insulating layer (**24**) which is arranged to cover both the first electrode and the second electrode, and in which a liquid repellent property on a surface thereof changes according to an electric potential difference between the first and second electrodes and an electroconductive liquid droplet on the surface; and the opening of the fluid passage is closed by transporting the liquid droplet to an area at which the first electrode is arranged, and the opening of the fluid passage is opened by transporting the liquid droplet to an area at which the second electrode is arranged.

According to the valve of the present invention, the liquid droplet is transported between an area at which the first electrode is arranged and an area t which the second electrode is arranged, by changing the liquid repellent property (wetting angle) on the surface of the insulating layer covering the first electrode and the second electrode, by changing an electric potential of the first electrode and the second electrode. Moreover, the opening of the fluid passage is closed by transporting the liquid droplet to the area at which the first electrode is arranged, whereas, the opening of the fluid passage is opened by transporting the liquid droplet to the area at which the second electrode is arranged. In other words, it is possible to open and close the fluid passage by a simple structure formed by the two electrodes and the insulating layer.

According to the present invention, there is provided an ink cartridge which includes the valve (**11**) of the present invention. In this case, it is possible to open and close an atmosphere-communication hole of the ink cartridge by the valve of the present invention. Consequently, it is possible to prevent effectively the drying of the ink, by closing the atmosphere-communication hole when the ink is not supplied from the ink cartridge to a destination of supply, and by opening the atmosphere-communication hole when the ink is supplied.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic structural view of an ink-jet printer according to a first embodiment of the present invention;

FIG. **2** is a vertical cross-sectional view of an ink cartridge;

FIG. **3**A is a plan view showing a liquid droplet transporting section of the first embodiment;

FIG. **3**B is a cross-sectional view taken along a line IIIB-IIIB in FIG. **3**A;

FIG. **3**C is a plan view showing a modification of an arrangement direction of split electrodes in FIG. **3**A;

FIG. **3**D is a cross-sectional view taken along a line IIID-IIID in FIG. **3**;

FIG. **3**E is a plan view corresponding to FIG. **3**A, of a liquid droplet transporting apparatus according to a first modification of the first embodiment;

FIG. **3**F is a cross-sectional view taken along a line IIIF-IIIF in FIG. **3**E;

FIG. **3**G is a plan view corresponding to FIG. **3**A of a liquid droplet transporting apparatus according to a second modification of the first embodiment;

FIG. **3**H is a cross-sectional view taken along a line IIIH-IIIH in FIG. **3**G;

FIG. **4** is a block diagram showing an electrical structure of the ink-jet printer according to the first embodiment;

FIG. **5** is a diagram showing schematically a circuit formed by a second electrode, an insulating layer, and a liquid droplet, in a state in which a liquid droplet exists in an area in which the second electrode is arranged;

FIG. **6**A is a diagram showing a plan view of the liquid droplet transporting section in the state in which a liquid droplet exists in an area in which a first electrode is arranged;

FIG. **6**B is a cross-sectional view taken along a line VIB-VIB in FIG. **6**A;

FIG. **7**A is a plan view showing the liquid droplet transporting section immediately before transporting the liquid droplet to the second electrode;

FIG. **7**B is a cross-sectional view taken along a line VIIB-VIIB in FIG. **7**A;

FIG. **8**A is a plan view showing the liquid droplet transporting section during transporting the liquid droplet to the second electrode;

FIG. **8**B is a cross-sectional view taken along a line VIIIB-VIIB in FIG. **8**A;

FIG. **9**A is a plan view showing the liquid droplet transporting section immediately after transporting the liquid droplet to the second electrode;

FIG. **9**B is a cross-sectional view taken along a line IXB-IXB in FIG. **9**A;

FIG. **10**A is a plan view showing the liquid droplet transporting section in the state in which the liquid droplet exists in the area in which the second electrode is arranged;

FIG. **10**B is a cross-sectional view taken along a line XB-XB in FIG. **10**A;

FIG. **11** is a vertical cross-sectional view of an ink cartridge when an atmosphere-communication hole is closed;

FIG. **12** is a vertical cross-sectional of the ink cartridge when the atmosphere-communication hole is open;

FIG. **13**A is a plan view showing a liquid droplet transporting section in which a liquid repellent film is formed on outside the two electrodes, in a fourth modification of the first embodiment;

FIG. **13**B is a cross-sectional view taken along a line XIIIB-XIIIB in FIG. **13**A;

FIG. **14**A is a plan view showing a liquid droplet transporting section in which a flat shape of the two electrodes is deformed, in the fourth modification of the first embodiment;

FIG. **14**B is a cross-sectional view taken along a line XIVB-XIVB in FIG. **14**A;

FIG. **15**A is a plan view showing a liquid droplet transporting section in which the liquid repellent film is formed between the two electrodes, in the fourth modification of the first embodiment;

FIG. **15**B is a cross-sectional view taken along a line XVB-XVB in FIG. **15**A;

FIG. **16**A is a plan view showing a liquid droplet transporting section in which the liquid repellent film is formed on outside the two electrodes, and between the two electrodes, in the fourth modification of the first embodiment;

FIG. **16**B is a cross-sectional view taken along a line XVIB-XVIB in FIG. **16**A;

FIG. **17**A is a plan view showing a liquid droplet transporting section in which a part of the liquid repellent film formed between the two electrodes is projected toward each of the electrode, in the fourth modification of the first embodiment;

FIG. **17**B is a cross-sectional view taken along a line XVIIB-XVIIB in FIG. **17**A;

FIG. **18** is a cross-sectional view of an ink-jet head and a nozzle cap (immediately before mounting the nozzle cap) according to a second embodiment;

FIG. **19**A is a plan view showing a liquid droplet transporting section according the second embodiment;

FIG. **19**B is a cross-sectional view taken along a line XIXB-XIXB in FIG. **19**A;

FIG. **20** is a block diagram showing an electrical structure of an ink-jet printer of the second embodiment;

FIG. **21** is a cross-sectional view of the ink-jet head and the nozzle cap (when the nozzle cap is mounted);

FIG. **22**A is a partial plan view of a memory according to a third embodiment;

FIG. **22**B is a cross-sectional view taken along a line XXIIB-XXIIB in FIG. **22**A;

FIG. **23** is a block diagram showing an electrical structure of the memory of the third embodiment;

FIG. **24**A is a partial plan view of a display unit according to a fourth embodiment;

FIG. **24**B is a cross-sectional view taken along a line XXIVB-XXIVB in FIG. **24**A; and

FIG. **25** is a block diagram showing an electrical structure of the display unit of the fourth embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

First Embodiment

A first embodiment of the present invention will be described below. The first embodiment is an example in which the present invention is applied to a valve for opening and closing an atmosphere-communication hole, of an ink cartridge.

Firstly, an ink-jet printer **100** in which an ink cartridge **5** is mounted will be described briefly. As shown in FIG. **1**, the ink-jet printer **100** includes a carriage **2** which is movable in a left and right direction in FIG. **1**, a serial ink-jet head **1** which is provided on the carriage **2** and discharges an ink onto a recording paper P, transporting rollers **3** which transport the recording paper in a frontward direction in FIG. **1**, and a control unit **4** (refer to FIG. **4**) which controls each component of the ink-jet printer **100**.

The ink-jet head **1** is connected to the ink cartridge **5** which stores the ink, via a tube **6**. Moreover, the ink-jet head **1** moves integrally with the carriage **2** in the left and right direction, and records desired characters, images, and the like on the recording paper P by jetting the ink from nozzles (omitted in the diagram) arranged on a lower surface thereof. Moreover, the recording paper P with the images and the like recorded thereon by the ink-jet head **1** is discharged in the frontward direction by the transporting rollers **3**.

Next, the ink cartridge **5** will be described. As shown in FIG. **2**, the ink cartridge **5** includes a cartridge body **10** which has an ink accommodating space **12** and a valve **11** which opens and closes a atmosphere-communication hole **19** which communicates the ink accommodating space **12** and the atmosphere.

The cartridge body **10** is formed to be rectangular parallelepiped shape, of a synthetic resin material (such as polypropylene) having higher ink wettability. Moreover, the ink accommodating space **12** which accommodates an ink I, and an atmosphere-entering channel **13** which communicates with an upper portion of the ink accommodating space **12** are formed in the cartridge body **10**. More concretely, the ink accommodating space **12** and the atmosphere-entering channel **13** are isolated by a partition wall **14** which extends from a bottom surface up to near a ceiling surface of the cartridge body **10**, and communicate via a gap **15** between an upper edge of the partition wall **14** and the ceiling surface of the cartridge body **10**.

The ink accommodating space **12** communicates with an ink supply hole **16** which is formed as a through hole in a bottom wall **10***a* of the cartridge body **10**. Moreover, the ink supply hole **16** is connected to an ink supply pipe **18** of the ink-jet printer **100** via a sealing member **17**. In other words, the ink I in the ink accommodating space **12** is supplied to the ink-jet head **1** via the ink supply hole **16** and the ink supply pipe **18**.

The atmosphere-entering channel **13** communicates with the atmosphere-communication hole **19** (fluid passage, atmosphere-entering channel) which penetrates the bottom wall **10***a* of the cartridge body **10**. Therefore, when the ink I in the ink accommodating space **12** is discharged (supplied to the ink-jet head **1**), the atmosphere enters into an upper portion of the ink accommodating space **12** via the atmosphere-communication hole **19** and the atmosphere-entering channel **13**. In order to prevent the ink I in the ink accommodating space **12** from drying and thickening as much as possible, the atmosphere-communication hole **19** is opened by the valve **11** only when the ink-jet printer **100** is used (at the time of an ink jetting operation of the ink-jet head **1**), and is closed when the ink-jet printer **100** is not used. This will be described later in detail, together with the following description of the vale **11**.

Next, the valve **11** will be described below. The valve **11** includes a liquid droplet transporting section **20** (liquid droplet transporting apparatus) which transports a liquid droplet **21** which is electroconductive, on an inner surface (upper surface) of the bottom wall **10***a* of the cartridge body **10**, between two positions namely a position overlapping with an upper end opening **19***a* of the atmosphere-communication hole **19** (closing the opening **19***a*) and a position shifted away from the upper end opening **19***a*. Moreover, an arrangement is made such that by transporting the liquid droplet **21** between the two positions by the liquid droplet transporting section **20**, an opening and closing of the atmosphere-communication hole **19** is switched. Furthermore, at an upper side of the liquid droplet transporting section **20**, a protective section **28** which prevents an ink mist from falling directly on the electroconductive liquid droplet **21**, is provided.

Here, as the liquid droplet **21** which is electroconductive, it is possible to use a liquid droplet **21** of a liquid such as water, and an aqueous solution in which glycerin or the like is dissolved. Or, it is also possible to use an ionic liquid (room temperature molten salt) made of only ions. Since this ionic liquid is nonvolatile in general, there is an advantage that it is hardly evaporated even when exposed to the atmosphere for a long time.

As shown in FIG. **3**A and FIG. **3**B, the liquid droplet transporting section **20** includes a first electrode **22** which is arranged on an upper surface of the bottom wall **10***a* of the cartridge body **10** made of a synthetic resin material, at an area which includes an upper end opening **19***a* of the atmosphere-communication hole **19**, a second electrode **23** which is arranged on the upper surface of the bottom wall **10***a* same as the first electrode **22**, apart from the first electrode **22**, and an insulating layer **24** which is formed on the upper surface of the bottom wall **10***a*, to cover completely both the first electrode **22** and the second electrode **23**.

The first electrode **22** has a substantially square and flat shape. Moreover, in a plan view, the upper end opening **19***a* of the atmosphere-communication hole **19** is positioned at almost center of the first electrode **22**. Consequently, when the liquid droplet **21** exists in an area at which the first electrode **22** is arranged, the atmosphere-communication hole **19** is closed assuredly (completely) by the liquid droplet **21** (refer to FIG. **6**A and FIG. **6**B). In the present invention the "area at which the first electrode is arranged" means an area on the insulating layer, overlapping with the first electrode. In this embodiment, a length of one side of the first electrode **22** is approximately 1 mm to 2 mm, and a diameter of the upper end opening **19***a* is approximately 0.3 mm. In order that the liquid droplet **21** does not flow into the atmosphere-communication hole **19**, it is preferable that a wetting angle of an inner surface of the atmosphere-communication hole **19** is not less than 90 degrees.

Moreover, the second electrode **23** also has a substantially square and flat shape similarly as the first electrode **22**, and is arranged on a right side of the first electrode **22** in FIG. **3**A, apart from the first electrode **22**. Furthermore, the second electrode **23** is divided into two split electrodes **23***a* (second electrode) and **23***b* (third electrode) of the same shape arranged to be isolated mutually. The two split electrodes **23***a* and **23***b* are arranged symmetrically with respect to a straight line L which passes through a center of gravity of the first electrode **22** and a center of gravity of the second electrode **23**. The two split electrodes **23***a* and **23***b*, as shown in FIG. **3**C and FIG. **3**D, may be arranged in a direction same as the direction in which the first electrode **22** and the second electrode **23** are arranged. In other words, the second electrode **23** may be divided in a direction orthogonal to a direction in which the first electrode **22** and the second electrode **23** are arranged. In this embodiment, a length of one side of the second electrode **23** is approximately 1 mm to 2 mm.

Moreover, with the ink-jet cartridge **5** mounted on the ink-jet printer **100**, the first electrode **22**, and the two split electrodes **23***a* and **23***b* of the second electrode **23** are connected independently to an electric potential applying section **25** (electric potential applying mechanism, refer to FIG. **4**) which is provided in the ink-jet printer **100**, and a predetermined electric potential is applied to these electrodes **22** and **23** (**23***a* and **23***b*) from the electric potential applying section **25**. The electric potential applying section **25** applies the same electric potential simultaneously to the two split electrodes **23***a* and **23***b* which form the second electrode **23**.

The insulating layer **24** is a thin film having a comparatively higher liquid repellent property, which is made of a material such as a fluororesin, a polyimide resin, and an epoxy resin. Moreover, the insulating layer **24** is formed on an entire predetermined area of an inner surface of the bottom wall **10***a*, which includes an area at which the first electrode **22** is arranged and an area at which the second electrode **23** is arranged. In other words, as shown in FIG. **3**A and FIG. **3**B, the insulating layer **24**, in addition to the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged, is also formed in an area **24***a* outside the first electrode **22** and the second electrode **23** (first liquid repellent film), and also formed in an area **24***b* between the first electrode **22** and the second electrode **23** (second liquid repellent film). In the present invention, the "area at which the second electrode is arranged" means an area on the insulating layer, overlapping with the second electrode.

With the electroconductive liquid droplet **21** existing on a surface of the insulating layer **24**, when an electric potential difference occurs between the liquid droplet **21** and the electrode (the first electrode **22** or the second electrode **23**), the larger the potential difference becomes, the lower the liquid repellent property (wetting angle) on the surface of the insulating layer **24** becomes (electrowetting phenomenon).

Therefore, the electric potential applying section **25** is structured to apply different electric potential to each of the first electrode **22** and the second electrode **23**, based on a command from the control unit **4** (valve control section **31**) of the ink-jet printer **100**, and the liquid droplet **21** is transported between the two areas by letting to differ the liquid repellent property of the insulating layer **24** between the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged.

To describe more concretely, the electric potential applying section **25** applies to one of the first electrode **22** and the second electrode **23**, a predetermined electric potential which is not a ground electric potential, and applies to the other electrode of the first electrode **22** and the second electrode **23**, the ground electric potential. Consequently, the liquid repellent property on a surface of a portion of the insulating layer **24** covering one of the electrodes to which the predetermined electric potential is applied is declined to be lower than the liquid repellent property of a portion covering the other electrode to which the ground electric potential is applied, and the liquid droplet **21** moves from the area at which the other electrode is arranged, to the area at which the one of the electrodes is arranged.

As shown in FIG. **3**A and FIG. **3**B, two ground electrodes **27** are arranged on a portion of the insulating layer **24** covering the first electrode **22** and the second electrode **23**, and these two ground electrodes **27** are kept all the time at the ground electric potential. Moreover, since the liquid droplet **21** which exists on the area at which the first electrode **22** is arranged or the area at which the second electrode **23** is arranged makes a contact with the ground electrode **27**, the electric potential of the liquid droplet **21** is kept at the ground electric potential and is not fluctuated (changed).

Incidentally, the two split electrodes **23***a* and **23***b* of the second electrode **23** are connected to a liquid droplet position detector **26** which detects an electrostatic capacitance between the two split electrodes **23***a* and **23***b*. As shown in FIG. **3**A, the two split electrodes **23***a* and **23***b* are arranged symmetrically with respect to the straight line L passing through the center of gravity of the first electrode **22** and the center of gravity of the second electrode **23**. In this case, when the liquid droplet **21** is transported from the area at which the first electrode **22** is arranged to the area at which the second electrode **23** is arranged, the liquid droplet **21** is positioned such that the liquid droplet **21** is spread over the two split electrodes **23***a* and **23***b*. In other words, the liquid droplet **21** is positioned between the two split electrodes **23***a* and **23***b* while making a contact with the two split electrodes **23***a* and **23***b* (refer to FIG. **9**A and FIG. **9**B). At this time, a condenser is formed by the split electrodes **23***a* and **23***b*, the electroconductive liquid droplet **21**, and the insulating layer **24** (dielectric substance) sandwiched between the liquid droplet **21** and the split electrodes **23***a* and **23***b*. In other words, it is possible to indicate a system formed by the two split electrodes **23***a* and **23***b*, the insulating layer **24**, and the liquid droplet **21** as a circuit which is formed by two condensers C**1** and C**2** connected in series as shown in FIG. **5**.

In other words, when the liquid droplet **21** exists on the area at which the second electrode **23** is arranged, an electrostatic capacitance (for example about 40 nF when a thickness of the insulating layer **24** made of a fluororesin is 0.5 μm) of the condensers C**1** and C**2** between the two split electrodes **23***a* and **23***b* is detected by the liquid droplet position detector **26**. On the other hand, when the liquid droplet **21** is not on the area at which the second electrode **23** is arranged (when positioned on the area at which the first electrode **22** is arranged), as compared to a case in which the liquid droplet **21** is positioned on the area at which the second electrode **23** is arranged, the electrostatic capacitance detected by the liquid droplet position detector **26** is decreased (becomes low) or becomes zero depending on a distance between the two split electrodes **23***a* and **23***b*.

Consequently, in this embodiment, the liquid droplet position detector **26** is structured to be capable of detecting whether the liquid droplet **21** exists on the area at which the first electrode **22** is arranged or on the area at which the second electrode **23** is arranged, based on the electrostatic capacitance detected between the two split electrodes **23***a* and **23***b*. More concretely, when a detected value of the electrostatic capacitance is not less than a predetermined value, the liquid droplet position detector **26** makes a judgment that the liquid droplet **21** exists on the area at which the second electrode **23** is arranged, and that the atmosphere-communication hole **19** is open. On the other hand, when the detected value of the electrostatic capacitance is less than the predetermined value (for example, a value close to 0), the liquid droplet position detector **26** makes a judgment that the liquid droplet **21** does not exist on the area at which the second electrode **23** is arranged (exists on the area at which the first electrode **22** is arranged), and that the atmosphere-communication hole **19** is closed. In other words, the two split electrodes function as sensors which cooperate to sense the presence of the liquid droplet.

Next, a liquid droplet transporting operation of the liquid droplet transporting section **20** will be described by referring to FIG. **6**A to FIG. **10**B. In FIG. **6**A to FIG. **10**B, "+" indicates that a predetermined electric potential is applied to the electrode, and "GND" indicates that the ground electric potential is applied to the electrode.

As shown in FIG. **6**A and FIG. **6**B, in a state in which the liquid droplet **21** exists on the area at which the first electrode **22** is arranged, the atmosphere-communication hole **19** is closed by the liquid droplet **21**. Moreover, the ground electric potential is applied to each of the first electrode **22** and the second electrode **23** (two split electrodes **23***a* and **23***b*), and the liquid droplet **21** with a wide wetting angle, is accommodated in the area at which the first electrode **22** is arranged. The liquid droplet **21** is in contact with the ground electrode **27**, and is kept at the ground electric potential. A diameter of the liquid droplet **21** may be such that the liquid droplet **21** is not protruding out from the first electrode **22** and the second electrode **23**, and in this embodiment the diameter of the liquid droplet **21** is approximately 1 mm to 2 mm.

From a state in FIG. **6**A and FIG. **6**B, in a case of transporting the liquid droplet **21** to the area at which the second electrode **23** is arranged, firstly, as shown in FIG. **7**A and FIG. **7**B, a predetermined electric potential is applied to the first electrode **22** by the electric potential applying section **25**. As a result, since an electric potential difference is generated between the first electrode **22** to which the predetermined electric potential is applied and the liquid droplet **21** which is kept at the ground electric potential, the liquid repellent property (wetting angle of the liquid droplet **21**) of the insulating layer **24** in the area at which the first electrode **22** is arranged, is declined, and the liquid droplet **21** is spread wetting up to an area between the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged.

Next, as shown in FIG. **8**A and FIG. **8**B, the electric potential applying section **25** switches the electric potential of the first electrode **22** from the predetermined electric potential to the ground electric potential, and at the same time switches the electric potential of the second electrode **23** from the ground electric potential to the predetermined electric potential. As a result, the liquid repellent property of the insulating layer **24** in the area at which the first electrode **22** is arranged is improved and the liquid repellent property of the insulating layer in the area at which the second electrode **23** is arranged is declined. Therefore, the liquid droplet **21** which has been spread wetting up to the area between the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged, moves toward the second electrode **23** having the lower liquid repellent property, and as shown in FIG. **9**A and FIG. **9**B, the atmosphere-communication hole **19** is opened.

Further, when the liquid droplet **21** is moved completely to the area at which the second electrode **23** is arranged, as shown in FIG. **10**A and FIG. **10**B, the electric potential of the second electrode **23** is switched from the predetermined electric potential to the ground electric potential by the electric potential applying section **25**. As a result, the liquid repellent property of the area at which the second electrode **23** is arranged is improved, the wetting angle of the liquid droplet **21** becomes wide (is increased), and the liquid droplet **21** is accommodated in the area at which the second electrode **23** is arranged.

Conversely, as shown in FIG. **10**A and FIG. **10**B, with the liquid droplet **21** existing on the area at which the second electrode **23** is arranged, and the atmosphere-communication hole **19** open, when the predetermined electric potential is applied to the first electrode **22** and at the same time, the ground electric potential is applied to the second electrode **23** by the electric potential applying section **25**, the liquid droplet **21** moves from the area at which the second electrode **23** is arranged to the area at which the first electrode **22** is arranged, and as shown in FIG. **6**A and FIG. **6**B, the atmosphere-communication hole **19** is closed by the liquid droplet **21**.

Next, an electrical structure of the ink-jet printer **100** by referring mainly to the control unit **4** will be described by referring to a block diagram in FIG. **4**. The control unit **4** includes a CPU which is a central processing unit, a ROM (Read Only Memory) in which computer programs and data for controlling each section of the ink-jet printer are stored, a RAM (Random Access Memory) which stores temporarily data processed by the CPU, and the like. Moreover, as shown in FIG. **4**, the control unit **4** includes a head control section **30** which controls an ink jetting operation of the ink-jet head **1**, and a valve control section **31** which controls an opening and closing operation of the valve **11**.

The head control section **30** controls the ink-jet head **1**, based on a printing data which is input from a PC **33** and makes the ink-jet head **1** to jet the ink onto the recording paper P, and makes the ink-jet head **1** to record predetermined characters and image on the recording paper P.

Moreover, the valve control section **31** controls the valve **11** to open and close the atmosphere-communication hole **19**. The atmosphere-communication hole **19** is opened only when the ink jetting operation of the ink-jet head **1** is performed, and is closed when the ink jetting operation is not performed.

To describe concretely, as shown in FIG. **11**, with the atmosphere-communication hole **19** closed, when a print command is input from the PC **33**, the valve control section **31**, before the ink-jetting operation of the ink-jet head **1** is performed, outputs to the electric potential applying section **25** a signal to open the atmosphere-communication hole **19**. At this time, the electric potential applying section **25** applies the ground electric potential to the first electrode **22**, and the predetermined electric potential to the second electrode **23**.

As a result, as shown in FIG. **12**, the liquid droplet **21** is transported from the first electrode **22** to the second electrode **23**, and the atmosphere-communication hole **19** is opened.

Moreover, when the recording on the recording paper P is completed, the valve control section **31** outputs to the electric potential applying section **25** a signal to close the atmosphere-communication hole **19**. At this time, the electric potential applying section **25** applies the predetermined electric potential to the first electrodes **22** and the ground electric potential to the second electrode **23**. As a result, as shown in FIG. **11**, the liquid droplet **21** is transported from the second electrode **23** to the first electrode **22**, and the atmosphere-communication hole **19** is closed by the liquid droplet **21**. In this manner, the valve **11** opens the atmosphere-communication hole **19** only when the ink is jetted from the ink-jet head **1**. Therefore, there is no shortage of supply of the ink I to the ink-jet head **1**, and it is possible to prevent effectively the drying (thickening) of the ink.

Moreover, as it has been described above, the electrostatic capacitance between the two split electrodes **23***a* and **23***b* is detected by the liquid droplet position detector **26**, and the position of the liquid droplet (in other words, the open or closed state of the atmosphere-communication hole **19**) is detected based on the electrostatic capacitance which is detected. Further, this detection result is output to the valve control section **31**.

Consequently, the valve control section **31** is capable of monitoring the open and closed state of the atmosphere-communication hole, according to the detection result detected by the liquid droplet position detector **26**. The valve control section **31**, based on the observation result, is capable of controlling the valve **11** not only at the time of a recording operation described above, but also at the time of a purge operation. For example, when the ink cartridge **5** is removed from the ink-jet printer **100** and installed again, a detector which detects installing and removing of the ink cartridge detects a time for which the ink cartridge **5** was removed from the ink-jet printer **100**. Furthermore, when the time for which the ink cartridge **5** was removed is more than a predetermined value, a judgment is made that drying of the ink in the ink cartridge **5** is progressing, and the purge operation is carried out. At this time, when a detection result that the atmosphere-communication hole **19** is closed is output by the liquid droplet position detector **26**, it is necessary to open the atmosphere-communication hole **19** for performing the purge. Therefore, the valve control section **31** outputs to the electric potential applying section **25**, a signal for opening the atmosphere-communication hole **19**. On the other hand, when a detection result that the atmosphere-communication hole **19** is closed is output, the purge may be carried out with the atmosphere-communication hole **19** in an open state as it has been. Therefore, the valve control section **31** does not output a signal to the electric potential applying section **25**, and the atmosphere-communication hole **19** is kept to be in the open state as it has been till the purge is carried out. Moreover, when the time for which the ink cartridge **5** was removed is not more than the predetermined value, it is not necessary to carry out the purge operation. Consequently, when a detection result that the atmosphere-communication hole **19** is open is output by the liquid droplet position detector **26**, the valve control section **31** outputs a signal to close the atmosphere-communication hole **19** to the electric potential applying section **25**. On the other hand, when a detection result that the atmosphere-communication hole **19** is closed is output, the valve control section **31** does not output a signal to the electric potential applying section **25**, and the atmosphere-communication hole **19** is kept to be in a closed state till the subsequent recording operation or the purge operation.

According to the first embodiment described above, the following effect is achieved. By applying different electric potential to the first electrode **22** and the second electrode **23** to differ the liquid repellent property (wetting angle) on the surface of the insulating layer **24** covering the first electrode **22** and the second electrode **23**, it is possible to transport the liquid droplet **21** from an area having a higher liquid repellent property to an area having a lower liquid repellent property, between the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged. In other words, by (using) the liquid droplet transporting section **20** having a simple structure formed by the two electrodes **22** and **23** (the first electrode **22** and the second electrode **23**), and the insulating layer **24**, it is possible to open and close the atmosphere-communication hole **19**. Moreover, since the ground electrode **27** which is kept at the ground electric potential is arranged in each of the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged, the electric potential of the liquid droplet **21** is kept all the time at the ground electric potential. Consequently, since the electric potential difference between the first electrode **22**, the second electrode **23**, and the liquid droplet **21** is stable, it is possible to perform assuredly the operation of transporting the liquid droplet **21**.

Furthermore, since the second electrode **23** is divided into two split electrodes **23***a* and **23***b* arranged to be isolated mutually, it is possible to detect whether the liquid droplet **21** exists on the area at which the first electrode **22** is arranged or on the area at which the second electrode **23** is arranged, based on the electrostatic capacitance between the two split electrodes **23***a* and **23***b*.

Moreover, by applying the present invention to the valve **11** which opens and closes the atmosphere-communication hole **19** of the ink cartridge **5**, it is possible to close the atmosphere-communication hole **19** by transporting the liquid droplet **21** to the first electrode **22** when the ink is not supplied from the ink cartridge **5** to the ink-jet head **1**. On the other hand, it is possible to open the atmosphere-communication hole **19** by transporting the liquid droplet **21** to the second electrode **23** when the ink is not supplied. In other words, by using the valve **11** or the liquid droplet transporting apparatus **20** having a simple structure, it is possible to prevent effectively the drying (thickening) of the ink without causing an insufficiency of the ink supply.

Next, modifications in which various modifications are made in the first embodiment described above, will be described below. Same reference numerals are assigned to components having basically the same structure as in the first embodiment, and description of such components is omitted.

First Modification

In the first embodiment, the second electrode **23** was divided into two split electrodes **23***a* and **23***b*, and arranged with the first electrode **22**, on the upper surface **10***b* of the bottom wall **10***a* of the cartridge body **10**. However, as shown in FIGS. **3**E and **3**F, a single second electrode **123** may be arranged with the first electrode **22**, on the upper surface **10***b* of the bottom wall **10***a* of the cartridge body **10**, and a third electrode **124** different from the second electrode **123** may be arranged in parallel to the upper surface **10***b* of the bottom wall **10***a*, isolated from the second electrode **123**. In this case, each of the one of the split electrodes **23***a*, and the other split electrode **23***b* in the first embodiment corresponds to the second electrode **123** and the third electrode **124** in the first modification. FIG. **3**E and FIG. **3**F are diagrams showing an arrangement relation of the second electrode **123** and the third electrode **124**. FIG. **3**E is a top view of the liquid droplet transporting apparatus **20**, and FIG. **3**F is a cross-sectional view taken along a line IIIF-IIIF in FIG. **3**E.

In the liquid droplet transporting apparatus **20** of the first modification, the atmosphere-communication hole **19** is formed in the bottom wall **10***a* of the cartridge body **10** similarly as in the first embodiment. The first electrode **22** is arranged on the upper surface **10***b* of the bottom wall **10***a*. Moreover, the single second electrode **123** having a rectangular shape is arranged apart from the first electrode **22** on the upper surface **10***b* of the bottom wall **10***a*. The insulating layer **24** is formed such that both the first electrode **22** and the second electrode **123** are completely covered. Two ground electrodes **27** are arranged on a portion of the insulating layer **24** covering the first electrode **22** and the second electrode **123**. Furthermore, a third electrode **124** is arranged in parallel to the upper surface **10***b* of the bottom wall **10***a* to face the second electrode **123**. In other words, when the liquid droplet transporting apparatus **20** is viewed from a top (upper side of a paper surface in FIG. **3**E), the third electrode **124** is arranged to cover the second electrode **123**. (in FIG. **3**E, the second electrode **123** completely overlaps the third electrode **124**). The third electrode **124** and the second electrode **123** have the same rectangular flat shape. Each of the third electrode **124** and the second electrode **123** is connected to the liquid droplet position detector **26** shown in FIG. **4**. The liquid droplet position detector **26** detects an electrostatic capacitance between the second electrode **123** and the third electrode **124**.

According to the principle described in the first embodiment, when the liquid droplet **21** is transported from the first electrode **22** to the second electrode **123**, the liquid droplet **21** exists between the second electrode **123** and the third electrode **124** facing the second electrode **123**, and is in contact with both the second electrode **123** and the third electrode **124**. At this time, a condenser is formed by the second electrode **123**, the third electrode **124**, the electroconductive liquid droplet **21**, and the insulating layer **24**. Consequently, when the liquid droplet **21** exists on the second electrode **123**, a predetermined electrostatic capacitance is detected between the second electrode **123** and the third electrode **124**, by the liquid droplet position detector **26**. On the other hand, when the liquid droplet **21** is not on the second electrode **123**, either the electrostatic capacitance is not detected by the liquid droplet position detector **26**, or the detected value of the electrostatic capacitance is substantially lower than the predetermined value. In other words, according to the first modification, by measuring the electrostatic capacitance, it is possible to detect whether or not the liquid droplet **21** exists on the second electrode **123**. Moreover, when the liquid droplet transporting apparatus **20** is viewed from the top, since the third electrode **124** is arranged to cover the second electrode **123**, when the liquid droplet **21** is on the second electrode **123**, even if the liquid droplet **21** is positioned away from a center of the second electrode **123** (even if a center of the liquid droplet **21** does not coincide with a center of the second electrode **123**), the third electrode **124** can make a contact with the liquid droplet **21**. Consequently, even when the liquid droplet **21** exists at a position shifted away from the center of the second electrode **123**, it is possible to detect assuredly the presence of the liquid droplet **21**. The insulating layer **24** is formed on the first electrode **22** and the second electrode **123** similarly as in the first embodiment. Therefore, even when the insulating layer **24** is not formed on a surface of the third electrode **124**, facing the second electrode **123**, by applying different electric potential to the first electrode **22** and the second electrode **123**, it is possible to transport the liquid droplet **21** between the area at which the first electrode **22** is arranged and an area at which the second electrode **123** is arranged.

In the first modification, a gap (distance) between the third electrode **124** and the insulating layer **24** may be such that the third electrode **124** can assuredly make a contact with the liquid droplet **21** when the liquid droplet exists on the second electrode **123**. Moreover, the third electrode **124** has a rectangular flat shape similar to the shape of the second electrode **123** in the first modification. However, the flat shape of the third electrode **124** may be different from the flat shape of the second electrode **123**, provided that the third electrode **124** assuredly makes a contact with the liquid droplet **21** when the liquid droplet **21** exists on the second electrode **123**.

Second Modification

A second modification in which modifications are made in the first modification will be described below by referring to FIG. **3**G and FIG. **3**H. FIG. **3**G and FIG. **3**H are diagrams showing an arrangement relation of the second electrode **123** in the first modification, and a third electrode **224**. FIG. **3**G is a top view of the liquid droplet transporting apparatus **20**, and FIG. **3**H is a cross-sectional view taken along a line IIIH-IIIH in FIG. **3**H. The second modification differs from the first modification at a point that the two ground electrodes **27** do not exist in the liquid droplet transporting apparatus **20**. Moreover, when the liquid droplet transporting apparatus **20** is viewed from the top (upper side of the paper surface in FIG. **3**G), it differs from the liquid droplet transporting apparatus **20** in the first modification at a point that the third electrode **224** extends up to the upper end opening **19***a* of the atmosphere-communication hole **19**, in other words the third electrode **224** extends to cover a part of the second electrode **123**. Furthermore, the third electrode **224** is always kept at the ground electric potential. Each of the third electrode **224** and the second electrode **123** is connected to the liquid droplet position detector **26** shown in FIG. **4**. The liquid droplet position detector **26** detects an electrostatic capacitance between the second electrode **123** and the third electrode **224**. Since the rest of the structure being similar to the structure in the first modification, the description thereof is omitted.

In the second modification, the third electrode **224** extends in parallel to the upper surface **10***b* of the bottom wall **10***a*, to face a part of the first electrode **22**, and the second electrode **123**. Therefore, the third electrode **224** makes a contact with the liquid droplet **21** even when the liquid droplet exists on the area at which the first electrode is arranged, and even when the liquid droplet exists on the area at which the second electrode **123** is arranged. Moreover, the third electrode **224** is always kept at the ground electric potential. Therefore, as in the first embodiment described above, the ground electrode **27** is not required to be provided separately. According to the principle described in the first embodiment, when the liquid droplet **21** is transported from the first electrode **22** to the second electrode **23**, the liquid droplet **21** exists between the second electrode **123** and the third electrode **224** facing the second electrode **123**, and makes a contact with both the second electrode **123** and the third electrode **224**. As a result, a condenser made of the second electrode **123**, the third electrode **224**, the liquid droplet **21**, and the insulating layer **24** is formed. Consequently, when the liquid droplet **21** exists on the second electrode **123**, a predetermined electrostatic capacitance is detected by the liquid droplet position detector **26**. On the other hand, when the liquid droplet **21** is not on the second electrode **123**, either the electrostatic capacitance is not detected by the liquid droplet position detector **26**, or an extremely small (low) electrostatic capacitance is detected by the liquid droplet position detector **26**. According to the principle described above, even in the second modification, it is possible to detect whether or not the liquid droplet **21** exists on the second electrode **123**, by using a liquid droplet transporting apparatus **20** having a simple structure. Furthermore, since the ground electrode is not required to be provided separately, the number of components is decreased, and it is possible to form the valve **11** and the liquid droplet transporting apparatus **20** having a simple structure. Consequently, it is possible to reduce a manufacturing cost.

Third Modification

In the first embodiment, the second electrode **23** is divided into two split electrodes **23***a* and **23***b*. However, instead of the second electrode **23**, the first electrode **22** may be divided. Moreover, both the first electrode **22** and the second electrode **23** may be divided. Furthermore, it not particularly necessary that the first electrode **22** and the second electrode are divided into two, and may be divided into a plurality of split electrodes more than two. On the other hand, when it is not necessary to detect the position of the liquid droplet **21**, it is not necessary that both the first electrode **22** and the second electrode **23** are divided. Moreover, when a fluctuation (change) in the electric potential of the liquid droplet **21** is sufficiently small with respect to the predetermined electric potential which is applied to the first electrode **22** and the second electrode **23**, and there is almost no effect on the transporting of the liquid droplet **21**, the ground electrode **27** which is for keeping the liquid droplet **21** at the ground electric potential, may be omitted.

Fourth Modification

It is desirable that the liquid droplet transporting section **20** is capable of preventing the liquid droplet **21** from moving due to vibration of the liquid droplet **21** and the like, to an area outside the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged, or an area at which an electrode on an opposite side is arranged. For example, as shown in FIG. **13**A and FIG. **13**B, a liquid repellent film **40** (first liquid repellent film) having a liquid repellent property higher than the liquid repellent property of the insulating layer **24** all the time, may be formed on an area outside the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged, so as to surround both the areas at which the two electrodes (the first electrode **22** and the second electrode **23**) are arranged. According to this structure, the movement of the liquid droplet **21** to the outside the area at which the electrode is arranged is prevented by the liquid repellent film **40**. As shown in FIG. **13**B, the liquid repellent film **40** may be formed to overlap the insulating layer **24**, or the insulating layer **24** may not be formed on the area outside the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged, and the liquid repellent film **40** may be formed directly on the surface of the bottom wall **10***a* (substrate).

Moreover, as shown in FIG. **14**A and FIG. **14**B, a structure may be such that, a width of an end portion on a side where the first electrode **22** and the second electrode **23** are adjacent may be narrowed, and between the first electrode **22** and the second electrode **23**, a width of an area in which the liquid repellent film **40** is not formed may be narrowed locally. In this structure, since the width of the area in which the liquid droplet **21** moves becomes narrow between the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged, the liquid droplet **21** hardly moves abruptly to the electrode on the opposite side, due to vibration, or the like.

Or, as shown in FIG. **15**A and FIG. **15**B, a liquid repellent film **41** (second liquid repellent film) having a liquid repellent property higher than the liquid repellent property of the insulating layer **24** all the time, may be formed in the area between the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged. In this structure, the abrupt movement of the liquid droplet **21** due to vibration or the like to the electrode on the opposite side is prevented by the liquid repellent film **41**. Moreover, the liquid repellent film **41**, similarly as the liquid repellent film **40** described above (refer to FIGS. **13**A and **13**B, and FIGS. **14**A and **14**B), may be formed to overlap the insulating layer **24**, or may be formed directly on the surface of the bottom wall **10***a*.

Furthermore, as shown in FIG. **16**A and FIG. **16**B, the liquid repellent film **40** may be formed on the upper surface of the insulating layer **24**, on the outer side of the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged, and the liquid repellent film **41** may be arranged between the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged. According to this structure, both the movement of the liquid droplet **21** to the outside of the areas at which the electrodes (first electrode **22** and the second electrode **23**) are arranged, and the movement of the liquid droplet **21** to the area on the opposite side at which the electrode is formed is prevented.

When a polyimide resin or an epoxy resin is used as the (for the) insulating layer **24**, and on the other hand a fluororesin is used for the liquid repellent films **40** and **41**, it is possible to make the liquid repellent property of the liquid repellent films **40** and **41** to be higher than the liquid repellent property of the insulating layer **24**.

Moreover, if a wetting angle of the liquid droplet **21** on the surface of the insulating layer **24** is more than 90 degrees, a surface roughness of the liquid repellent films **40** and **41** may be more than a surface roughness of the insulating layer **24** since the liquid droplet **21** hardly moves abruptly even when there is vibration. On the other hand, when the wetting angle of the liquid droplet **21** on the surface of the insulating layer **24** is less than 90 degrees, since the liquid droplet **21** tends to move abruptly due to vibration, it is preferable that the surface roughness of the liquid repellent films **40** and **41** is less than the surface roughness of the insulating layer **24**.

Moreover, when the liquid repellent film **41** is formed between the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged, the liquid repellent film **41** becomes a primary resistance for liquid droplet transporting between the first electrode **22** and the second electrode **23**. Therefore, it is preferable to generate a transporting force which is capable of making the liquid droplet **21** cross over the liquid repellent film **41**, by setting to be comparatively higher the electric potential of the electrode to which the liquid droplet is transported to decline sufficiently the liquid repellent property on the area at which that electrode is formed,

Or, as shown in FIG. **17**A and FIG. **17**B, a part of the liquid repellent film **41** (second liquid repellent film) provided between the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged, may be projected toward each of the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged. According to this structure, the abrupt movement of the liquid droplet **21** to the electrode on the opposite side due to vibration or the like is prevented by the liquid repellent film **41**, and when the liquid droplet **21** is transported between the areas at which the two electrodes (the first electrode **22** and the second electrode **23**) are arranged, the liquid droplet **21** easily crosses over the liquid repellent film **41** from a portion projected toward areas in which the electrodes are arranged, and it is possible to move the liquid droplet **21** smoothly between the area at which the first electrode **22** is arranged and the area at which the second electrode **23** is arranged.

As it has been described above by referring to FIG. **13**A to FIG. **17**B, an embodiment in which the second electrode **23** is not divided is shown. However, it is needless to mention that even when the second electrode **23** is divided, the abovementioned structure is applicable.

Fifth Modification

The valve **11** may be structured such that the atmosphere-communication hole **19** is opened at regular intervals. When the printing is not performed for a long time, the atmosphere-communication hole **19** is not opened for a long time by the valve **11**. Therefore, due to a temperature change and a pressure change in the atmosphere, there is a possibility of an excessive rise in a pressure, or generation of a negative pressure in the ink accommodating space **12** in the cartridge body **10**. Therefore, when a structure is made such that when a judgment is made by the head control section **30** of the control unit **4** that a predetermined time has elapsed from a time at which the previous printing was completed, the valve control section **31** outputs to the electric potential applying section **25** a signal for opening the atmosphere-communication hole **19**, the atmosphere-communication hole **19** is opened periodically (for a fixed interval), and an a difference in pressure inside and outside the cartridge body **10** is suppressed to be small.

Sixth Modification

In the first embodiment, the electric potential applying section **25** which applies the electric potential to the first electrode **22** and the second electrode **23**, and the liquid droplet position detector **26** which detects the position of the liquid droplet **21** from the electrostatic capacitance between the two split electrodes **23***a* and **23***b*, are provided at the side of the ink-jet printer **100**. However, the electric potential applying section **25** and the liquid droplet position detector **26** may be provided at the side of the ink cartridge **5**, and may be connected to the control unit **4** (valve control section **31**) on a side of the ink-jet printer **100**. In other words, the valve **11** of the ink cartridge **5** may be provided with the liquid droplet transporting section **20** which includes the electric potential applying section **25** and the liquid droplet position detector **26**.

Second Embodiment

Next, a second embodiment of the present invention will be described below. The second embodiment is an example in which the present invention is applied to a nozzle cap which is mounted on an ink jetting surface **1***a* of the ink-jet head **1**. Same reference numerals are assigned to components having a structure similar as in the first embodiment, and the description of such components is omitted.

Similarly as in the first embodiment (refer to FIG. **1**), the ink-jet head **1** jets the ink onto the recording paper P (recording medium) while moving in a direction orthogonal to the direction in which the recording paper P is carried. Moreover, the carriage **2** is structured to be movable up to a retracting position which is on a further outside in a width direction (left and right direction in FIG. **1**), of an area in which the recording paper P is transported. Moreover, a nozzle cap **60** is installed at this retracting position, and this nozzle cap **60** is driven up and down by a cap driving section **55** (refer to FIG. **20**). When the ink is not (to be) jetted from a nozzle **52** (refer to FIG. **18**), the ink-jet head **1** and the carriage **2** move integrally to the retracting position. At the retracting position, the nozzle cap **60** is mounted on the ink-jet head **1** to cover from a lower side, a lower surface of the ink-jet head **1** (ink jetting surface **1***a*) in which discharge ports **52***a* of a plurality of nozzles **52** are arranged.

As shown in FIG. **18**, the ink-jet head **1** includes a manifold **50**, a plurality of individual channels **51** which are branched from the manifold **50**, and the plurality of nozzles **52**, which are provided at an end of the individual channels **51** respectively, and which open in the lower surface (ink jetting surface **1***a*) of the ink-jet head **1**. The ink is supplied to the manifold **50** from an external ink tank (omitted in the diagram) via an ink supply hole **53** provided at an upper side of the manifold **50**. Moreover, the ink is supplied from the manifold **50** to the nozzles **52** via the individual channels **51**, and the ink is jetted from the nozzles **52**.

The nozzle cap **60** includes a cap **61** which covers the nozzles **52** from the lower side, a lip **62** having a ring shape, which extends upward from a peripheral portion of the cap portion **60**, and is in contact with the ink jetting surface **1***a*, and a base **63** which supports the cap **61** from a lower side.

The cap **61** has an area more than an area of the ink jetting surface **1***a* in which the discharge ports **52***a* are arranged, such that it is possible to cover at a time, all the discharge ports **52***a* of the nozzles **52** from the lower side. Moreover, the lip **62** is in contact throughout, around the area of the ink jetting surface **1***a* in which the discharge ports **52***a* are arranged, and is capable of sealing the discharge ports **52***a*. The cap **61** and the lip **62** are formed of an elastic material such as a synthetic resin material.

A communication hole **65** (communication passage) in the form of a through hole which communicates an internal space **64** (a space on a side of the ink jetting surface **1***a*) of the cap **61** and an outside (atmosphere) penetrates a bottom wall **63***a* (base material) of the base **63**. This communication hole **65** is for relieving a rise in pressure in the internal space **64**, and preventing a meniscus in the nozzle **52** from being destroyed at the time of mounting the nozzle cap **60**. However, even when the nozzle cap **60** is mounted, if the internal space **64** communicates with outside, the ink in the nozzle **52** dries with the elapsing of time. Therefore, a valve **66** which opens and closes the communication hole **65** is provided to the base **63**.

This valve **66** has a structure almost similar to the valve **11** (refer to FIG. **2** and FIG. **3**) of the first embodiment. In other words, the valve **66** includes the liquid droplet transporting section **20** which transports an electroconductive liquid droplet **21**, on an inner surface (upper surface) of the bottom wall **63***a*. As shown in FIG. **19**, this liquid droplet transporting section **20** includes the first electrode **22** which is arranged on an inner surface (upper surface) of the bottom wall **63***a* to surround an upper end opening **65***a* of the communication hole **65**, the second electrode **23** which is arranged on the same upper surface of the bottom wall **63***a*, apart from the first electrode **22**, and the insulating layer **24** which is formed on the upper surface of the bottom wall **63***a*, to cover completely (entirely) both the first electrode **22** and the second electrode **23**. Moreover, the second electrode **23** is divided into two split electrodes **23***a* and **23***b* arranged to be isolated mutually. At the upper side of the liquid droplet transporting section **20**, a protective section **67** which prevents the ink mist from falling directly on the electroconductive liquid droplet **21**, is provided.

When the electric potential applying section **25** applies different electric potential (predetermined electric potential or ground electric potential) to each of the first electrode **22** and the second electrode **23**, based on the command from the control unit **4** (valve control section **69**) of the ink-jet printer **100**, the liquid repellent property on the area at which one of the electrodes is arranged, is declined. Therefore, the liquid droplet **21** is transported between the two areas at which the electrodes are arranged. Moreover, when the liquid droplet **21** is transported to the area at which the first electrode **22** is arranged, the communication hole **65** is closed by the liquid droplet **21**, and when the liquid droplet **21** is transported to the area at which the second electrode is arranged, the communication hole **65** is opened.

Furthermore, the two split electrodes **23***a* and **23***b* of the second electrode **23** are connected to the liquid droplet position detector **26**. The liquid droplet position detector **26** detects whether the liquid droplet **21** exists on the area at which the first electrode **22** is arranged or on the area at which the second electrode **23** is arranged (in other words, the open or closed state of the communication hole **65**), based on the electrostatic capacitance between the two split electrodes **23***a* and **23***b*.

As shown in FIG. **20**, the control unit **4** of the ink-jet printer **100** includes the CPU, the RAM, the ROM, and the like. Moreover, the control unit **4** includes the control section **30** which controls the ink-jet head **1** to jet the ink, based on the printing data which is input from the PC **33**, a cap control section **68** which controls the cap driving section **55** to make the nozzle cap **60** ascend and descend, and the valve control section **69** which opens and closes the valve **66** by controlling the nozzle cap **60**.

At the time of mounting the nozzle cap **60** on the ink-jet head **1**, the valve control section **69**, before mounting the nozzle cap **60**, outputs to the electric potential applying section **25**, a signal to open the communication hole **65**. At this time, the electric potential applying section **25** applies the ground electric potential to the first electrode **22**, and the predetermined electric potential to the second electrode **23**. As a result, as shown in FIG. **18**, the liquid droplet is transported from the first electrode **22** to the second electrode **23**, and the communication hole **65** is opened. Therefore, the pressure rise in the internal space **64** in the cap **61** is relieved, and the meniscus formed in the nozzle **52** is prevented from being destroyed.

On the other hand, after the nozzle cap **60** is mounted on the ink-jet head **1**, the valve control section **69** outputs to the electric potential applying section **25**, a signal to close the communication hole **65**. At this time, the electric potential applying section **25** applies the predetermined electric potential to the first electrode **22**, and applies the ground electric potential to the second electrode **23**. As a result, as shown in FIG. **21**, the liquid droplet **21** is transported from the second electrode **23** to the first electrode **22**, and the communication hole **65** is closed by the liquid droplet **21**. Therefore, the ink in the nozzle **52** is prevented from being dried.

Furthermore, even when the nozzle cap **60** is removed from the ink-jet head **1** (isolated from the ink jetting surface **1***a*), the valve control section **69**, immediately before the nozzle cap **60** is removed, may output to the electric potential applying unit **25** a signal to open the communication hole **65**. In this case, it is possible to reduce a pressure fluctuation in the internal space **64** in the cap **61** when the nozzle cap **60** is separated from the ink jetting surface **1***a*. Therefore, the destruction of the meniscus is further prevented.

According to the structure of the second embodiment described above, it is possible to prevent the drying of the ink and destruction of the meniscus, by the liquid droplet transporting section **20** having a simple structure formed by the first electrode **22**, the second electrode **23**, and the insulating layer **24**. Moreover, since the second electrode **23** is divided into two split electrodes **23***a* and **23***b* arranged to be isolated mutually, it is possible to detect by the liquid droplet position detector **26**, whether the liquid droplet **21** exists on the area at which the first electrode **22** is arranged or on the area at which the second electrode **23** is arranged, based on the electrostatic capacitance between the two split electrodes **23***a* and **23***b*.

Even in the second embodiment, it is possible to make modifications similar to the modifications made in the first embodiment, in the liquid droplet transporting section **20** (such as division of electrodes and addition of the liquid repellent films **40** and **41** (refer to FIG. **13** to FIG. **17**)).

Third Embodiment

Next, third embodiment of the present invention will be described below. This third embodiment is an example in which, the present invention is applied to a memory which is a rewritable non-volatile memory.

As shown in FIG. **22**A and FIG. **22**B, a memory **70** includes a substrate **71** (base material) made of a synthetic resin material, a storage section **72** capable of storing a plurality of bit data, which is formed by a plurality of liquid droplet transporting sections **20** transporting an electroconductive liquid droplet **21**, across two areas on a surface of the substrate **71**, and a control section **73** which controls each of the liquid droplet transporting sections **20** (refer to FIG. **23**). In FIG. **22**A, three out of the plurality of liquid droplet transporting sections **20** are shown.

Each liquid droplet transporting section **20** of the storage section **72** has almost a similar structure as in the first embodiment. In other words, as shown in FIG. **22**A and FIG. **22**B, the liquid droplet transporting section **20** includes the first electrode **22** which is arranged on the surface of the substrate **71** made of a synthetic resin material, the second electrode **23** which is arranged apart from the first electrode **22** on the surface of the substrate **71** same as the first electrode **22**, and the insulating layer **24** which is formed on the surface of the substrate **71**, to cover completely both the first electrode **22** and the second electrode **23**. Moreover, the second electrode **23** is divided into two split electrodes **23***a* and **23***b* arranged to be isolated mutually. Furthermore, the ground electrode **27** is formed on the surface of the insulating layer **24**, in each of the area at which the first electrode **22** is arranged, and the area at which the second electrode **23** is arranged. The ground electrodes **27** of the plurality of liquid droplet transporting sections **20** are brought into conduction via a wire **74**, and all the ground electrodes **27** are kept all the time at the ground electric potential.

Moreover, as shown in FIG. **23**, each liquid droplet transporting section **20** includes the electric potential applying section **25** which applies the electric potential to the first electrode **22** and the second electrode **23**, and the liquid droplet position detector **26**. The electric potential applying section **25** applies different electric potential (predetermined electric potential or ground electric potential) to each of the first electrode **22** and the second electrode **23**, according to the data which is to be stored, and transports the liquid droplet **21** between the two areas at which the electrodes (the first electrode **22** and the second electrode **23**) are arranged. Concretely, a state in which the liquid droplet **21** exists on the area at which the first electrode **22** is arranged (state of the two liquid droplet transporting sections **20** on a lower side in FIG. **22**A) corresponds to "0" of the bit data, and a state in which the liquid droplet **21** exists on the area at which the second electrode **23** is arranged (state of the liquid droplet transporting section **20** on an uppermost side in FIG. **22**A) corresponds to "1" of the bit data. Furthermore, in one liquid droplet transporting section **20**, it is possible to store data of 1-bit (one bit) ("0" or "1") by transporting the liquid droplet **21** to one of the two areas at which the electrodes (the first electrode **22** and the second electrode **23**) are arranged.

Moreover, the liquid droplet position detector **26** detects whether the liquid droplet **21** exists on the area at which the first electrode **22** is arranged or on the area at which the second electrode **23** is arranged (in other words, which of "0" and "1" is stored), based on the electrostatic capacitance between the two split electrodes **23***a* and **23***b*, and outputs the result of detection to the control section **73**.

As shown in FIG. **23**, the control unit **73** is connected to an external data input-output unit **75**. When a plurality of bit data to be stored is input to the control section **73** from the data input-output unit **75**, the control section **73** outputs information related to the bit data ("0" or "1") which is to be stored to the electric potential applying section **25** of the plurality of liquid droplet transporting sections **20** corresponding to each of the plurality of bit data. Moreover, when the data to be stored is "0", the electric potential applying section **25** applies the predetermined electric potential to the first electrode **22**, and at the same time applies the ground electric potential to the second electrode **23**, and transports the liquid droplet **21** to the area at which the first electrode **22** is arranged (the two liquid transporting sections **20** at the lower side in FIG. **22**A). On the other hand, when the data to be stored is "1", the electric potential applying section **25** applies the ground electric potential to the first electrode **22**, and at the same time applies the predetermined electric potential to the second electrode **23**, and transports the liquid droplet **21** to the area at which the second electrode **23** is arranged (the liquid droplet transporting section **20** at the uppermost side in FIG. **22**A). In this manner, the plurality of bit data which is input is stored in the storage section **72**. When the transporting of the liquid droplet **21** is over, the electric potential of both the first electrode **22** and the second electrode **23** is switched to the ground electric potential, and since this state is maintained, the data which is stored is not erased even when a power supply of the memory **70** is switched off.

Moreover, information as to whether the liquid droplet **21** exists on the area at which the first electrode **22** is arranged or on the area at which the second electrode **23** is arranged is input to the control section **73** from the liquid droplet position detector **26** of the plurality of liquid droplet transporting sections **20**. In other words, the control section **73** is capable of detecting as to which data of "0" and "1" is stored by one liquid droplet transporting section **20** of the storage section **72**. Moreover, the control section **73** reads the data stored in the storage section **72**, according to a request from the data input-output unit **75**, and outputs to the data input-output unit **75**.

According to a structure in the third embodiment described above, it is possible to store the data of 1-bit (one bit) by the liquid droplet transporting section **20** having a simple structure formed by the two electrodes **22** and **23** (the first electrode **22** and the second electrode **23**), and the insulating layer **24**. Moreover, since the second electrode **23** is divided into two split electrodes **23***a* and **23***b* arranged to be isolated mutually, it is possible to detect by the liquid droplet position detector **26**, whether the liquid droplet **21** exists on the area at which the first electrode **22** is arranged or on the area at which the second electrode **23** is arranged, based on the electrostatic capacitance between the two split electrodes **23***a* and **23***b*. Consequently, it is possible to determine a data of 1-bit (one bit) which is stored, and to read the data. Furthermore, since the memory **70** according to the third embodiment uses a substrate made of a synthetic resin instead of a silicon substrate used in a normal semiconductor memory, it is possible to manufacture the memory **70** at a low cost.

Even in the third embodiment, it is possible to make modifications similar to the modifications made in the first embodiment, in the liquid droplet transporting section **20** (such as addition of the liquid repellent films **40** and **41** (refer to FIG. **13** to FIG. **17**)). However, for reading the data which is already stored in the storage section **72**, the minimum requirement is that at least one of the first electrode **22** and the second electrode **23** is divided into a plurality of split electrodes, and it is possible to detect whether the liquid droplet **21** exists on the area at which the first electrode **22** is arranged or on the area at which the second electrode **23** is arranged. In the third embodiment, the memory **70** is capable of storing bit data (two values (binary data) "0" and "1"), and by arranging a plurality of split electrodes each divided as the second electrode in an arrangement direction of the first electrode **22** and the second electrode **23**, the memory **70** is capable of storing multi-valued information such as three-valued (ternary data) information or higher-valued information.

Fourth Embodiment

Next, a fourth embodiment of the present invention will be described below. The fourth embodiment is an example in which the present invention is applied to a display unit which displays the desired characters, images, and the like.

As shown in FIG. **24**, a display unit **80** includes a substrate **81**, a display section **82** which is formed of the plurality of liquid droplet transporting sections **20** each transporting an electroconductive and colored liquid droplet **21** across two areas on a surface of the substrate **81** (base material), a cover plate **83** which is arranged facing the surface of the substrate **81**, and a control section **84** (refer to FIG. **25**) which controls each of the liquid droplet transporting sections **20** of the display section **82**. In FIG. **24**, three of the plurality of liquid droplet transporting sections **20**, are shown.

Each liquid droplet transporting section **20** of the display section **82** has almost a similar structure as in the first embodiment. In other words, as shown in FIG. **24**, the liquid droplet transporting section **20** includes the first electrode **22** which is arranged on the surface of the substrate **81**, the second electrode **23** which is arranged apart from the first electrode **22** on the surface of the substrate **81** same as the first electrode **22**, and the insulating layer **24** which is formed on the surface of the substrate **81**, to cover completely both the first electrode **22** and the second electrode **23**. Moreover, the second electrode **23** is divided into two split electrodes **23***a* and **23***b* arranged to be isolated mutually. Furthermore, the ground electrode **27** is arranged on the surface of the insulating layer **24**, in each of the area at which the first electrode **22** is arranged, and the area at which the second electrode **23** is arranged. The ground electrodes **27** of the plurality of liquid droplet transporting sections **20** are brought into conduction via a wire **85**, and all the ground electrodes **27** are kept all the time at the ground electric potential.

Moreover, as shown in FIG. **25**, each liquid droplet transporting section **20** includes the electric potential applying section **25** which applies the electric potential to the first electrode **22** and the second electrode **23**, and the liquid droplet position detector **26**. The electric potential applying section **25**, based on a command from the control section **84**, applies different electric potential (predetermined electric potential or ground electric potential) to each of the first electrode **22** and the second electrode **23**, and transports the liquid droplet **21** between the two areas at which the electrodes (the first electrode **22** and the second electrode **23**) are arranged. Moreover, the liquid droplet position detector **26** detects whether the liquid droplet **21** exists on the area at which the first electrode **22** is arranged or on the area at which the second electrode **23** is arranged, based on the electrostatic capacitance between the two split electrodes **23***a* and **23***b*, and outputs the result of detection to the control section **84**.

As shown in FIG. **24**, the cover plate **83** faces a surface of the substrate **81** on which the first electrode **22** and the second electrode **23** are arranged. Moreover, a transit hole (through hole) **83***a* in the form of a through hole penetrates the cover plate **83** at a position facing the first electrode **22**. Therefore, when viewed from a side of the cover plate **83** opposite to the substrate **81**, the area at which the first electrode **22** is arranged is seen through the transit hole **83***a*, but the area at which the second electrode **23** is arranged is blocked by the cover plate **83**. Consequently, in a state in which the color liquid droplet **21** exists on the area at which the first electrode **22** is arranged (state of the two liquid droplet transporting sections **20** at the lower side in FIG. **24**A), the color of the liquid droplet **21** is displayed, but in a state in which the color liquid droplet **21** exists on the area at which the second electrode **23** is arranged (state of the liquid droplet transporting section **20** at the upper side in FIG. **22**A), the color of the liquid droplet **21** is not displayed, and a color (such as a white color) of the insulating layer **24** which is a base material is displayed.

As shown in FIG. **25**, the control section **84** is connected to an external input unit **85**. Moreover, when data related to the characters, images, and the like which are to be displayed is input from the input unit **85** to the control section **84**, the control section **84** outputs a signal to display to the electric potential applying section **25** of the liquid droplet transporting section **20** corresponding to the characters, images, and the like to be displayed, from among the plurality of liquid droplet transporting sections **20** of the display section **82**. As a result, the electric potential applying unit **25** of the liquid droplet transporting section **20** to which the signal is input, applies the predetermined electric potential to the first electrode **22**, and at the same time applies the ground electric potential to the second electrode **23**, and transports the liquid droplet **21** to the area at which the first electrode **22** is arranged. At this time, the color of the liquid droplet **21** which is transported to the area at which the first electrode **22** is arranged is displayed through the transit hole **83***a* in the cover plate **83**.

Moreover, position information of the liquid droplet **21** which is detected by the liquid droplet position detector **26** is input to the control section **84**. Therefore, the control section **84** is capable of identifying the characters, images, and the like which are displayed practically, by the position information of this liquid droplet **21**.

According to the structure of the fourth embodiment described above, it is possible to display the desired characters, images, and the like by the liquid droplet transporting section **20** having a simple structure formed by the two electrodes **22** and **23** (the first electrode **23** and the second electrode **23**), and the insulating layer **24**. Moreover, since the second electrode **23** is divided into two split electrodes **23***a* and **23***b* arranged to be isolated mutually, it is possible to detect whether the liquid droplet **21** exists on the area at which the first electrode **22** is arranged or on the area at which the second electrode **23** is arranged, and to identify the characters, images, and the like which are practically displayed. Furthermore, the liquid droplet **21** does not move from the area at which the first electrode **22** is arranged or the area at which the second electrode **23** is arranged, unless different electric potential is applied to the first electrode **22** and the second electrode **23**. In other words, when the liquid droplet **21** exists on the area at which the first electrode **22** is arranged, and the color of the liquid droplet is displayed, since the liquid droplet **21** does not move to the area at which the second electrode **23** is arranged unless the electric potential applied to the first electrode **22** and the electric potential applied to the second electrode **23** is different, the display state is maintained. Moreover, when the liquid droplet **21** exists on the area at which the second electrode **23** is arranged, and the color of the liquid droplet is not displayed, the liquid droplet does not move to the area in which the first electrode **22** is arranged unless the electric potential applied to the first electrode **22** and the electric potential applied to the second electrode **23** are different, and the state in which the color of the liquid droplet is not displayed is maintained. In other words, for maintaining the same display condition, it is not necessary to supply the power supply all the time (continuously). Consequently, it is possible to maintain the same display state without consuming the electric power.

Even in the fourth embodiment, it is possible to make modifications similar to the modifications made in the first embodiment, in the liquid droplet transporting section **20** (such as division of electrodes and addition of the liquid repellent films **40** and **41** (refer to FIG. **13**A to FIG. **17**B)).

In addition to these modifications, it is possible to make further modifications such as following in the fourth embodiment described above. For example, when the cover plate is arranged to face only the area in which the second electrode **23** is arranged, and does not face the area in which the first electrode **22** is arranged, the transit hole **83***a* is not required to be formed in the cover plate **83**.

Moreover, when the first electrode **22** and the second electrode **23** are formed of a transparent ITO (indium-tin oxide) thin film, the insulating layer **24** is formed of an almost transparent fluororesin, and the substrate **81** is formed of a transparent material such as glass, the color of the liquid droplet **21** is displayed even when seen from a surface of the substrate **81** on the side opposite to the electrodes **22** and **23**. Therefore, in such case, the cover plate **83** may be arranged to face the surface of the substrate **81** on the side opposite to the electrodes **22** and **23** (lower side of the substrate **81** in FIG. **24**B).

Furthermore, the first electrode **22**, a portion of the substrate **81** in the area in which the first electrode **22** is arranged, and a portion of the insulating layer **24** in the area in which the first electrode **22** is arranged may be transparent, and on the other hand, at least one of the second electrode **23**, a portion of the substrate **81** in the area at which the second electrode **23** is arranged, and a portion of the insulating layer **24** in the area at which the second electrode **23** is arranged may be non-transparent (property of not letting light to pass through). In this structure, since the area at which the second electrode **23** is arranged is non-transparent, when viewed from the side of the substrate **81** opposite to the electrodes **22** and **23** (lower side of the substrate **81** in FIG. **24**B), the liquid droplet **21** which exists on the area at which the second electrode **23** is arranged is not seen, and therefore, the cover plate **83** is not necessary.

In the embodiments and the modifications described above, the description is made by giving examples of specific shapes, structures, and materials of the electrodes and the substrate. However, the present invention is not restricted to these shapes, structures, and materials, and it is possible to use arbitrary shapes, structures, and materials, provided that an effect of the present invention is achieved. The embodiments and the modifications described above are examples in which the present invention is applied to a valve or the like used in an ink-jet cartridge. However, embodiments to which the present invention is applicable are not restricted to these embodiments and the modifications. The liquid droplet transporting apparatus or the valve of the present invention is also applicable to a fluid supplying apparatus which supply a gas and a fluid used in micro robots and medical equipments.

What is claimed is:

1. A valve comprising:

a substrate having a fluid passage which has an opening on a surface of the substrate;

a first electrode which is arranged on the surface, of the substrate, at an area including the opening of the fluid passage;

a second electrode which is arranged apart from the first electrode on the surface of the substrate; and

an insulating layer which is arranged to cover both the first electrode and the second electrode, and in which a liquid repellent property on a surface thereof changes according to an electric potential difference between the first and second electrodes and an electroconductive liquid droplet on the surface;

wherein the opening of the fluid passage is closed by transporting the liquid droplet to an area at which the first electrode is arranged, and the opening of the fluid passage is opened by transporting the liquid droplet to an area at which the second electrode is arranged.

2. An ink cartridge which includes the valve as defined in claim **1**.

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